M.R.P. 1038
S.C. 111/229
7th February, 1957

Studies of eddy structure in the first few thousand feet of the atmosphere

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Part 1. Measurements of the vertical and horizontal (longitudinal) components

by

J. I. P. Jones and H. E. Butler

(Meteorological Office)

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AIR MINISTRY

METEOROLOGICAL RESEARCH COMMITTEE

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SUMMARY

Details are given of modifications to the instrument, previously described in M.R.P.974, for measuring vertical gustiness in the form of inclination and mean speed of the wind. A description is also given of an adaption of a sensitive airmeter for recording fluctuations of total wind speed. Both instruments, which have good response at periods down to about one second, are designed for mounting on the cable of a captive balloon.

A brief account is given of some recent observations made up to a maximum height of 7000 ft. at Cardington. Some examples of records covering a variety of meteorological conditions are presented.

1. INTRODUCTION

During the past year experimental equipment has been developed at C.D.E.E. for the study of the vertical component of turbulence at heights beyond the reach of towers and masts. In the first instance attention was concentrated on measurements of the fluctuations of wind inclination only, since it seemed probable that for many purposes an acceptable approximation to the fluctuations of the actual vertical component of velocity would then follow from a knowledge of the mean horizontal wind speed. The apparatus developed for this purpose, for use from a position on a captive balloon cable, was described in M.R.P.974. Since then minor modifications have been made to the apparatus and a more extensive study has been made of its response, and these features are discussed in Section 2(a) of this paper.

When it is required to deduce accurate values of the vertical component from the measurements of inclination, it is of course necessary to measure the fluctuation of horizontal or total wind speed. An Ower vane anemometer has recently been adapted for this purpose and the design and performance of the instrument are described in Section 2(b). Apparatus for measuring mean air temperature from the captive balloon cable has also been assembled and is described in Section 2(c).

It is now proposed to use the above equipment in carrying out two types of observations of eddy structure in the first few thousand feet of the atmosphere. In the first type attention will be confined to wind inclination (and mean wind speed) measurements, the aim being to accumulate statistics on the broad variations of vertical gustiness with height, time and synoptic conditions. The second type will be concerned with obtaining a more detailed description of the turbulent structure, in the form of the scale and energy

spectrum of the vertical component and the horizontal shearing stress. These observations will involve measurements of the fluctuations of both wind inclination and total speed, with corrections for the movements of the instrument supports, and will be carried out on a less regular basis than the first type of observation. A number of observations of both types have already been made, using captive balloon facilities at the Balloon Development Establishment, Cardington, Bedfordshire. The analysis of the results, especially those of the more elaborate observations, has yet to be completed, and various aspects of these will be discussed in subsequent papers of the present series. However, in view of the novel nature of the data which are being accumulated it was thought appropriate to give in Sections 3(a) and (b) of the present paper a description of the procedure and examples of the raw data, with some approximate root mean square values of wind inclination.

2. INSTRUMENTAL DETAILS

(a) Fluctuation of wind inclination

The principle of operation of the three instruments used for measuring wind inclination is similar to that described in M.R.P. 974, with minor modifications in design (see Fig.1(a)). Components of the electrical bridge circuit were housed inside the lower part of the control fin, A, and the overall length of the instrument was reduced by 6 inches to $31\frac{1}{2}$ inches. Wind tunnel tests were made to select the minimum clearance, B, for the inclination vane which gave free exposure with inclinations within the range $+40^\circ$ to -30°, and as a result the support, C, for the potentiometer was increased in length, by $2\frac{1}{2}$ in. to 8 in., from its fulcrum, D. The air meter, E, at the lower end of this support was of standard pattern (by Negretti and Zambra), but modified to operate an electrical changeover switch at approximately every 1000 ft. of airflow. The weight of the airmeter and the additional streamlined weight, F, maintained the support arm vertical in wind speeds up to 13 m/sec. The natural period of the pendulum was 0.9 sec. while critical damping by piston, G, prevented oscillatory motion. Fig. 2 shows the effect of initially deflecting the pendulum 20°, without and with the damper connected.

A counter-balance weight, H, restored loss of balance due to the small ($\frac{7}{8}$") off-setting of the main support arm from the balloon cable, and the addition of a hook, I, at the tail, provided an initial support for the electric cable (see Fig.5) and a fixing point for cables leading from instruments at a higher level.

The dimensions of the inclination vane remained 6" x 3" but the new models were lighter and weighed 0.16 oz. ($4\frac{1}{2}$ g.) including a 6" shaft, but not including the pivoted support and the counter-balance weight. Starting torque of the vane bearing (plain) and potentiometer was 0.055 oz. in. (4 g.cm.) and frictional effects, though adverse at very low wind speed, were not much in evidence at normal working speeds. Response tests were carried out at various wind speeds in a tunnel, by displacing the vane with a fine thread, to $+30^\circ$ relative to the air stream and releasing it instantaneously. Fig.3 shows the nature of the record obtained for six wind speeds over a range 6.6 to 0.8 m/s, and, for comparison, the response of the recorder alone. Though the vane was not dead-beat above about 3 m/s, over-shoot was not registered, owing to the slower response time of the recorder. Under usual working conditions (5 m/sec. or greater), the effective time of response was thus governed by that of the recorder (0.2 sec.), but at 2 m/s it increased to about 0.5 sec. The modified vertical gustiness meters were considered suitable for use in wind speeds within the range approximately 3 to 12 m/sec., the lower limit being governed by the inadequate response of the control fin, and the upper limit by vibrations of the balloon cable which occurred at times in high wind speeds.

In order to economise in electric connecting cable, the balloon tethering cable was used as a common conductor from the three vertical gustiness meters, and from a thermistor circuit for measuring mean air temperature. The remaining conductors were brought to a junction near the lowest instrument and from there formed the four conductors of a 5000 ft. length of light-weight cable. See Fig.6(b).

Records of gustiness were made on a three-channel ink recorder, (Everett Edgcumbe) with a chart width of 6.7 cm. per channel. Full scale deflection from the centre zero was $2\frac{1}{2}$ mA and the coil resistance was 600 ohms. The three direct-coupled amplifiers required to drive the recorder were built on the lines described in M.R.P.974, but were supplied with a stabilised high tension voltage of 250 V, and 6.3 V unstabilised AC for the valve heaters. However, with the use of the common conductor, and since all amplifiers were provided with power by the same supply, it was necessary to make "single ended" connections at the input end.

A three-pole switch, S_2 Fig.6(c), at the input to the amplifiers allowed recordings to be made of either inclination of each of the three vanes or the difference in the inclination of pairs of vanes. When S_2 was switched to the left the inclinations ϕ_1, ϕ_2 and ϕ_3 were recorded on the corresponding channels of the recorder, and when S_2 was right, while channel 1 remained unchanged, channel 2 recorded $\phi_2 - \phi_1$ and channel 3 gave $\phi_3 - \phi_2$. In these cases the required equality of the output voltage for a given inclination could be observed by comparing reference pulse heights on the same amplifier-recorder channel. Furthermore the balance of each amplifier was checked when S_2 was in the mid-position with S_1 closed. Under these conditions, when the same signal voltage was applied to both input terminals, a dynamically balanced amplifier would produce no output.

(b) Fluctuations of total wind speed

The function of the anemometer in the gustiness meter was firstly to provide reference pulses for the setting of sensitivity, and secondly to give wind speeds. The minimum period over which mean speeds could be measured was inversely proportional to wind speed and at 5 m/sec. was about 1 min. For shorter period fluctuations, a separate anemometer (shown in Fig.1(b)) was used. This was an Ower (see Ower, 1949, p.150) airmeter, K, with the gear train and dial removed, and with a miniature switch, L, fitted on the spindle of the rotor. Four contacts per revolution of the rotor were made, and the electric pulses produced were "counted" electrically over $2\frac{1}{2}$ sec. sequential periods and recorded as amplitudes. Provision was also made for continuously recording the pulse rate so that periods of shorter duration could be examined.

The performance of the anemometer was investigated in a wind tunnel, with various angles of pitch of the vanes, and its time of response measured on a high speed recorder. The pitch of 30° (relative to the airflow) which was finally chosen gave a response time (90%) from zero of 0.3 sec., and a rotational speed of approximately 12/sec. in a wind speed of 5 m/sec. Linearity of the calibration curve remained unchanged over a calibrated range of 1 to 10 m/sec., and the pulse rate (four times the rotational speed) varied from about 10/sec. at 1 m/sec. to 100/sec. at 10 m/sec.

Tests of the anemometer to a fluctuating speed were carried out in the tunnel by moving it to and fro at a controlled rate. The anemometer, guided by a rail, was moved along the airstream with approximately sinusoidal motion. This was effected with a 20 ft. length of string attached to the rotating arm of a constant speed motor, and an elastic return cord. Tests at two frequencies were made, by altering the gear ratio of the motor, and peak speeds of 1.0 m/sec. were used in both cases by adjusting the effective length of the rotating arm. Tracings of the records produced with a chart speed of 12 in./min. are shown in Figs. 4(a) and (b). In a mean wind speed of 5 m/sec. a peak-to-peak response of 90% was obtained with a period of 2.4 sec. and just over 70% when the period was 1.0 sec.

For operation on the balloon cable, the anemometer support was carried on double bearings, M, which allowed it to be freely directed into the mean wind under the action of a cylindrical fin, N. The total wind speed was thus measured, corrections being unnecessary for large excursions of the wind inclination from the horizontal (see Ower, 1949, page 152 for effect of yaw). The anemometer was connected to the ground equipment with a separate light-weight twin-core cable.

The electronic integrator (see Fig.7) consisted of a high speed relay, a storage and switching unit and a d-c amplifier. The relay, operated by an 18 V power supply and the anemometer switch, charged one of three equal condensers C_1 from a constant voltage supply, E, by step-transfer of charge via a small condenser C_2. The ratio of C_1 to C_2 was large (2000 : 1) so that the charging rate of C_1 was almost linear over a large range. Connections to the condensers C_1 were made through a 3-pole "snail" cam switch S_1, driven continuously by a mains synchronous motor at 1 revolution in $7\frac{1}{2}$ sec. Contacts 'a', 'b' and 'c' of this switch dropped from segment to segment in sequence, but separated in time by only about 1/100 sec. In the position shown in Fig.7 one of the 2 μF condensers C_1 was being charged through contact 'b', another was registering its voltage on the recorder through contact 'c' and the d-c amplifier, while the third had been discharged through 'a'.

Every $2\frac{1}{2}$ sec., 'a' dropped first, started discharge of the registering condenser and time marked the recorder. Contact 'b' followed and transferred charging to the newly discharged condenser, and finally contact 'c' operated, registering the voltage which the condenser under charge had acquired during the previous $2\frac{1}{2}$ sec. A manually operated switch S_2 allowed a negative bias to be applied to the condensers C_1, so that the full range of the recorder (centre zero) could be used on a scale of 0-10 m/sec. For a continuous registration of wind speed, within the limits of the anemometer response, condensers C_1 were replaced by a leaking condenser circuit, R_1 C_3, by means of switch S_3. Setting up and checking procedure included the operation of the relay at 50 c/s from a biased AC supply, with switch S_4. This allowed the short-term stability of the mains frequency to be checked, and adjustment of sensitivity to be made by altering the input voltage, E, to the integrator with potentiometer P.

(c) Mean air temperatures

A thermistor (Stantel type K 2361/120), mounted in a bakelite tube, J, (Fig.1(a)) was fitted in the upper part of the control fin of one of the instruments, for the measurement of air temperature. To make effective use of natural ventilation a low operating current was used, and the insulating mounting tube ($1\frac{1}{4}$ in. internal diameter, 6 in. long) and aluminium sides of the fin were utilised as radiation shields. At first the resistance of the thermistor was measured with a "Wheatstone's Bridge", and after deduction of the known cable resistance, converted to temperature from a laboratory calibration of the thermistor. This method of observing temperature was later changed to a direct reading method, with a bridge circuit mounted in the fin of the instrument, where the supply battery of the gustiness instrument was used for power. Components were arranged so that the out-of-balance current of the bridge had a near-linear relationship with temperature and gave full-scale deflection on a 20-0-20 μA meter over a temperature range of +30°F to +70°F. Fig. 6 shows the connection of the thermistor into the circuit. When switch S_1 is open, the output current Im passing through the meter M is given by the equation

$$Im = \frac{V(Rt - R_3)}{(Rt + R_3)(2Rm + R_4) + 2RtR_3}$$

where V = supply voltage to the bridge

Rt = resistance of thermistor

and Rm = total resistance in the external (meter) circuit.

R_3, (wire wound Eureka) was adjusted to balance the bridge at 50°F so that any error introduced by a change of V (Im $\propto$ V) was reduced to a percentage of the meter deflection from the centre of the scale. Thus a change in V from 3.0 to 2.9 would cause an error of -2/3 at 70, -1/3 at 60, 0 at 50, +1/3 at 40 and +2/3°F at 30°F. In practice it was evident from changes in the height of the reference pulse of the gustiness recorder that voltage

changes of this order did not occur. Variation in the resistance of the balloon cable from 0 to 5000 ft. was only 0.12% of Rm and could be ignored. The "live" conductor from bridge to meter (0.9% of Rm) was always in circuit and its resistance was taken into account when evaluating R_5, while variations due to its temperature coefficient of resistance were negligible in this circuit. An absolute accuracy of $\pm \frac{1}{2}^{\circ}F$ was achieved without the application of corrections, and changes of $0.1^{\circ}F$ could be measured. With this direct reading method it was possible to raise the instruments with little delay while making temperature readings at frequent intervals during the ascent, it being necessary to wait only about 1 min. for the thermistor to acquire ambient temperature.

(d) Movement of the balloon

A movement of the balloon, and hence of the instrument support, introduces errors into the recorded values of gustiness. The effect of the changing angle of the tethering cable due to this movement was eliminated from vertical gustiness measurements through the principle of operation of the instrument, while for total speed fluctuations the operation of the anemometer was independent of the cable angle. Errors caused by the bodily transfer of the instruments through the air were, however, present in the recordings from both instruments whenever significant movement of the balloon took place.

To minimise the effects of movements, and to enable approximate measurement of their value to be made easily, it was necessary to use a balloon which provided a substantial residual lift when at operating height. The tethering cable was thus maintained sensibly straight and calculations of the height of instruments could be made from a knowledge of the cable length and its angle, θ, from the vertical.

During experiments carried out at Cardington, a record of movement was made with the aid of a theodolite with a potentiometer coupled to its telescope, erected near the tethering point of the cable, (a power driven winch). A point on the cable, usually one of the instruments, was "followed" continuously when recordings of gustiness were being made. For measurement of height, a cosine potentiometer was used and $\cos\theta$ was recorded on a linear scale over a range 0.9 to 1.0. The full scale represented a height range of 10% of the distance, l, of an instrument from the winch (taken to be the length of cable) and a close approximation to height changes was given from changes in $l \cos\theta$. When total speed measurements were made the cosine potentiometer was replaced by a linear one, and the cable angle was recorded.

As would be expected, the effects of movement were smallest in the absence of large-scale turbulence at the balloon height. In conditions where there was little or no measurable vertical component of wind near the balloon, movement of the instruments was correspondingly small and in general no corrections were necessary for accurate interpretations of the records. This presented the best method of obtaining error-free measurements in turbulent air, i.e. by flying the balloon where possible in relatively stable air above the turbulent region, with the instruments attached to the cable at selected heights above the ground.

3. RECENT OBSERVATIONS

(a) Procedure

Observations have been carried out during the three periods 8th to 15th May, 26th to 30th June and 12th to 17th September, 1956. A van was adapted as a mobile laboratory in which all the equipment could be conveyed to a site at Cardington and in which the ground instruments could be operated. A mains supply of 240 volts A.C. was available to provide the electronic equipment with power.

/For

For the first two periods a modified Mk. 10 kite balloon was provided by the Balloon Development Establishment. This balloon had a capacity of 24,000 cu. ft. and a lift of about 7 cwt. near the ground. The tethering cable was of stranded steel with a breaking strain of $3\frac{1}{4}$ tons and weighing 100 lb. per 1000 ft. For the third period a Mk. 11 balloon was used. This was larger than the modified Mk. 10 and gave a lift of about 15 cwt. near the ground. Using similar cable the residual lift at 5000 ft. was about 10 cwt.

Three gustiness meters were attached to the balloon cable usually at spacings of 1000 ft. for recording actual wind inclinations, and at spacings of up to 400 ft. for recording the differences between the inclinations. Recordings were made at various heights up to a maximum of 7000 ft. The electric cable from a junction at the lowest gustiness meter to the ground was 5000 ft. long, and was stored on a drum with its inner end accessible. Connection to ground equipment could thus be made after any length had been paid out. During the second and third periods the highest gustiness meter was fitted with the thermistor for measuring temperatures. Generally, readings of temperature were taken every 250 ft. and the temperature structure was sampled at the rate of 1000 ft. in about 10 minutes. The total wind speed anemometer, described in 2(b), was available for the third period and was attached to the balloon cable just below the lowest gustiness meter. Two three-channel clockwork driven recorders and one single-channel recorder with an A.C. synchronous motor drive (Everett Edgcumbe) were used in various combinations to obtain the recordings.

The modified theodolite was set up conveniently near the balloon winch and was used to obtain a continuous recording of either the height or elevation of one gustiness meter.

In order to specify the meteorological conditions near the ground, temperature difference was measured with aspirated thermistors (Stantel type K 2361/120) between $\frac{1}{2}$ metre and 4 metres above the ground, the indicating meter and remote control of the aspirating motors being housed in the mobile laboratory. Total radiation flux was measured during the third period, using a radiometer built to the design described by J.MacDowall (1954), and at the same time readings of surface wind speed were taken using an electric cup anemometer.

(b) Examples of data and accuracy of records

Samples of some of the records taken in various meteorological conditions are shown in Figures 8 to 18, with additional meteorological information opposite each figure. This information includes a temperature sounding (dry bulb) plotted on a graph where the dry adiabatic lapse rate is indicated by a pecked line. For all examples, except the first, local temperature data from measurements with a thermistor, or from the Cardington "BALTHUM" sounding are used and are plotted against the length of cable from the winch. The heights quoted on the gustiness records are also cable-lengths, but can be regarded as the height above ground to within 3%. Accuracy of the gustiness records is governed by the degree of balloon movement which took place during the recordings. In some cases (Figures 14, 15 and 16) the recorded elevation of the instruments is shown, and an approximation of errors included in the gustiness traces may be deduced by assuming that the instruments always move in an arc centred at the winch and in the vertical plane of the mean wind direction. The correction, C_ϕ, to inclination will then be given by

$$C_\phi = \tan^{-1}\left[\frac{\pm S \sin(\theta+\phi)}{V \pm S\cos(\theta+\phi)}\right]$$

and the corrected total speed V_t by

$$V_t = \sqrt{V^2 + S^2 \pm 2VS\cos(\theta+\phi)}$$

where ϕ and V are respectively the apparent inclination and total speed of the wind, $(90-\theta)$ is the elevation of the instrument and S is the tangential speed of the instrument, approximately equal to $l\,d\theta/dt$ (l = cable length). The negative sign is used for decreasing θ.

In Figure 14, $d\theta/dt$ is a maximum at about 1638¼ B.S.T. and the correction to speed and inclination deduced from the above formulae is - 1.1 m/s and $< 1^\circ$ respectively. Thus whereas correction for the movement of the instrument in this instance caused a marked levelling of the recorded total wind speed, there was little effect on the inclination record. Similar considerations apply to Figure 16. On the other hand, from Figure 15 it is evident from the record of the instrument movement that little or no correction is necessary to either inclination or speed traces. It will be noted that total speed records in both Figures 14 and 15 are in histogram form, the height of each pulse representing the mean speed for the previous 2½ sec., whereas for the record of Figure 16 the storage circuit (Section 2(b)) has been switched out and the higher frequencies are apparent.

Recordings of instrument elevation were also made with the other examples of gustiness shown (Figures 8 to 13, 17 and 18), but are not given in this paper. It will, however, frequently be evident from the nature of the inclination records themselves that the general trend, as well as the higher frequency component, is reasonably true, as the three gustiness meters were always mounted on the same cable. Each would therefore be affected in a similar manner by a movement of the balloon, though to a degree in proportion to its height. Thus, there can be little doubt as to the reality of the convective turbulence indicated in Figure 8 at 3000 and 4000 ft. The long period (approx.7 min.) wave motion at 5000 ft. is also believed to be genuine as this cannot be accounted for by the effects of a balloon movement. The positive "bump" between 1207 and 1208 B.S.T. would however be flattened out and the mean after 1208¾ raised to about + 2°.

Figures 9 and 10 are samples taken from records made on one day, the former illustrating a period of well developed convection up to 3000 ft. at about noon and the latter, in two 6-min. periods, the results of decayed convection up to 6000 ft. in the evening. In Figure 9 the corrections for movement are such as to increase the positive inclination (balloon rising) by a few degrees for about 1 min. around 1141½ B.S.T. and to reduce the inclination for a period of ¾ min. around 1145. The steady downward component at 4000, 5000 and 6000 ft. in Figure 10 is also regarded as real and corrections would increase this component slightly as the balloon was falling steadily throughout the period. In contrast to the convective conditions of Figure 9, Figures 11 and 12 illustrate the low degree of turbulence recorded up to 3000 ft. in approaching warm front conditions during the night. No measurable error due to balloon movement was evident during these runs. R.M.S. values of wind inclination at 1000, 2000 and 3000 ft. for 20-min. periods during the day are given opposite Figure 9, and for comparison some R.M.S. values are shown opposite Figure 12 for the following early morning.

Differences of inclination between pairs of vanes are shown in Figure 13, together with the inclination at 2000 ft. In this case the three instruments were suspended one above the other at 2000, 2100 and 2150 ft., and differences over 100 and 50 ft. height intervals were recorded. During this sample period, the corrections to inclination for instrument movement are, in general, small, but rise to a peak of about -4° at 1126.8 B.S.T. For the records of differences, it is assumed that as the three instruments were closely spaced, the effects of movement would be roughly the same on all three when the differences of inclination are small, and that errors due to movement need not be taken into account. The results obtained on this occasion are the subject of a more detailed analysis in a separate report (M.R.P.1044). The remaining two figures given in this paper (Figures 17 and 18) are examples of vertical gustiness below and above a subsidence inversion of base around 3000 ft. and top 4000 ft. In this case the balloon was flying in stable air and recorded movement was small, giving maximum corrections of about 1°. It is noteworthy that the tension of the cable at ground level

was still about 4 cwt. with the balloon flying at 7000 ft. and the angle of the tethering cable lay within 6° of the vertical. Figure 17 shows a moderate degree of turbulence at 2000 ft. decreasing somewhat near the inversion base at 3000 ft. and damped out almost entirely at the inversion top at 4000 ft. A slow undulating motion with a period of about 5 min. is shown in Figure 18 at 5000 ft. with practically no vertical component above at 6000 ft. and very little at 7000 ft.

Acknowledgements

The instruments used in this investigation were made or adapted by Mr. H. Scamell and Mr. R. Penny. Acknowledgement is made to Mr. L.A. Speed and Mr. J. Long, of the Balloon Development Establishment, Cardington, for provision of balloon facilities.

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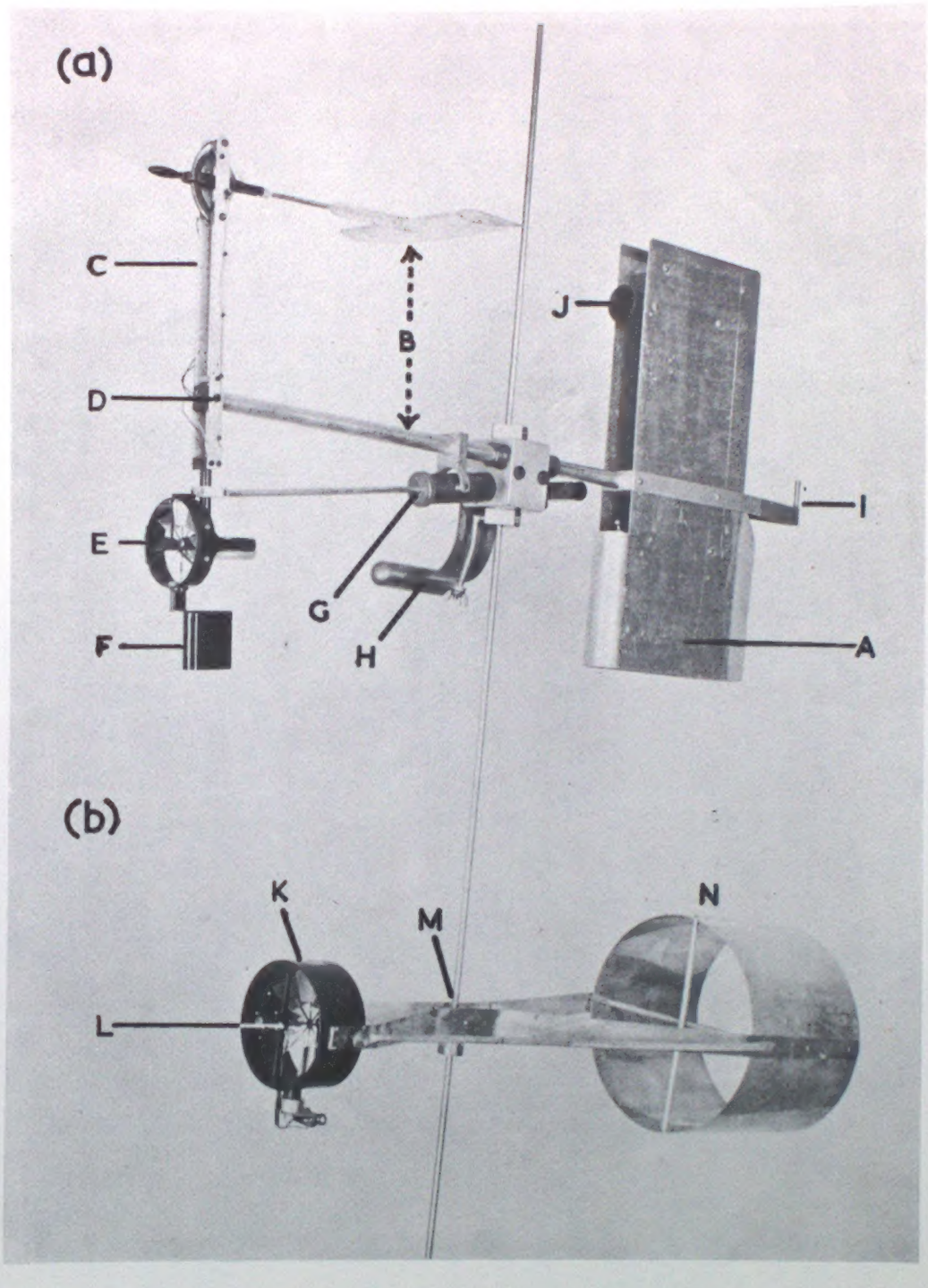


FIG. 1. (a) & (b)

T.1355.

MODIFIED GUSTINESS METER (TOP) AND "TOTAL SPEED" ANEMOMETER ON STEEL ROD TO RESEMBLE MOUNTING ON BALLOON CABLE.

P.T.P. 574.

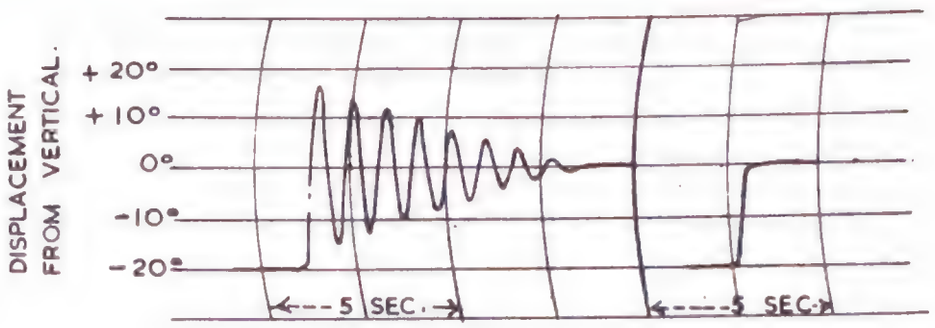


FIG. 2. ACTION OF PISTON IN DAMPING OSCILLATORY MOTION.

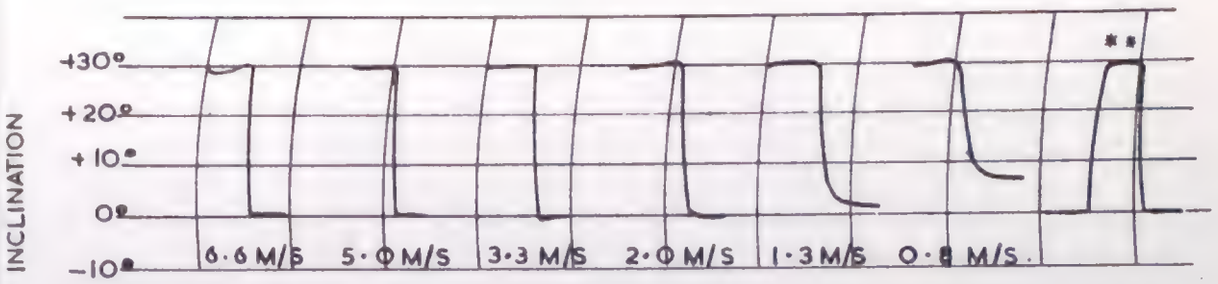


FIG. 3. RESPONSE TESTS OF INCLINATION VANE AT VARIOUS WIND SPEEDS.
TIME SCALE FOR EACH TEST IS 1 DIVISION = 2·5 SEC.
** RECORDER RESPONSE ONLY TO PULSE 1·25 SEC. DURATION.

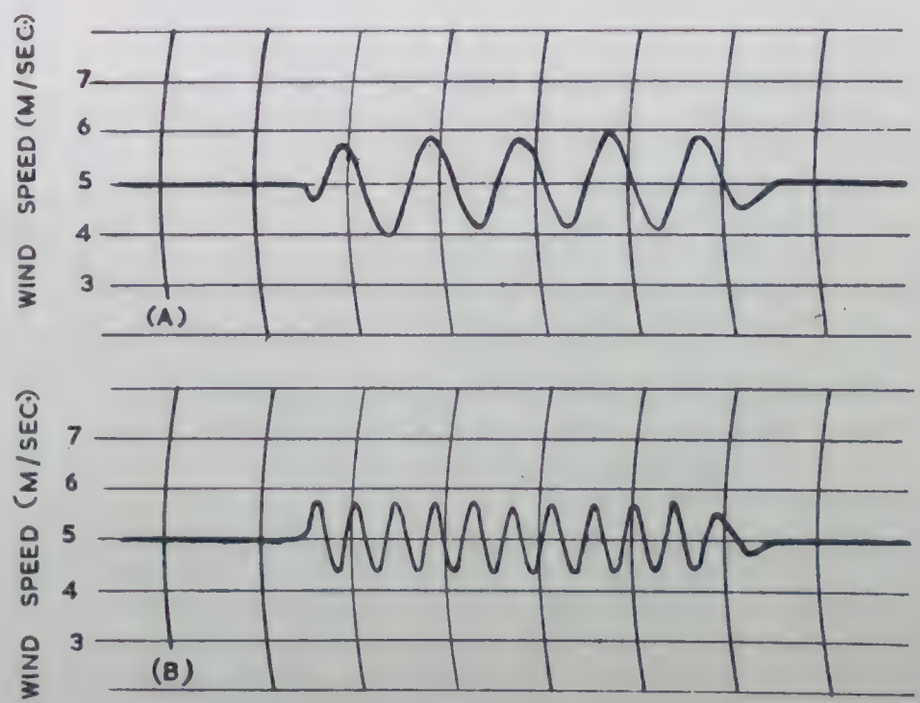


FIG 4 (A) AND (B). RECORD OF ANEMOMETER RESPONSE TO APPROXIMATELY SINUSOIDAL FLUCTUATIONS OF 2 M/SEC PEAK-TO-PEAK AMPLITUDE.
(A) PERIOD OF FLUCTUATION = 2·4 SEC.
(B) PERIOD OF FLUCTUATION = 1·0 SEC.

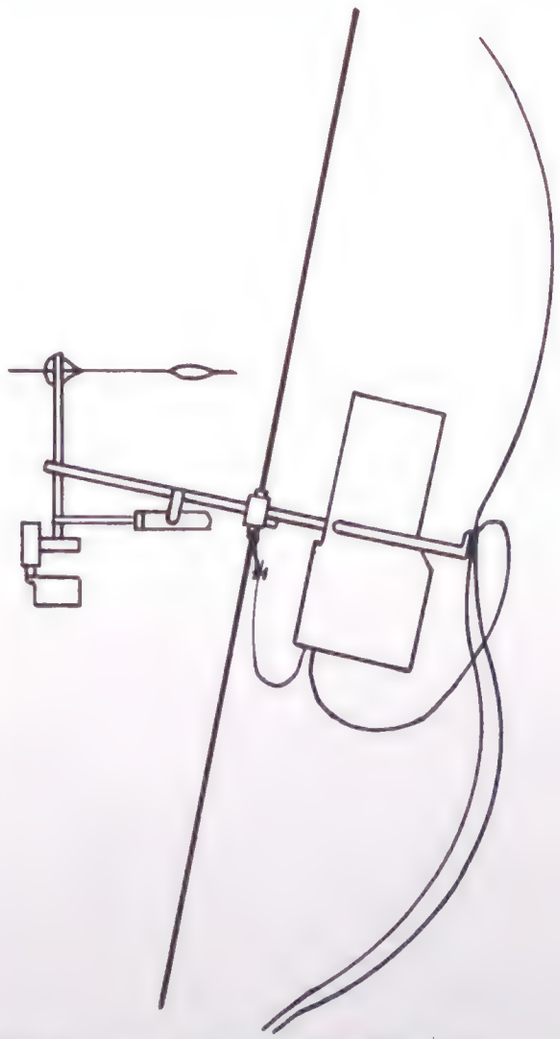
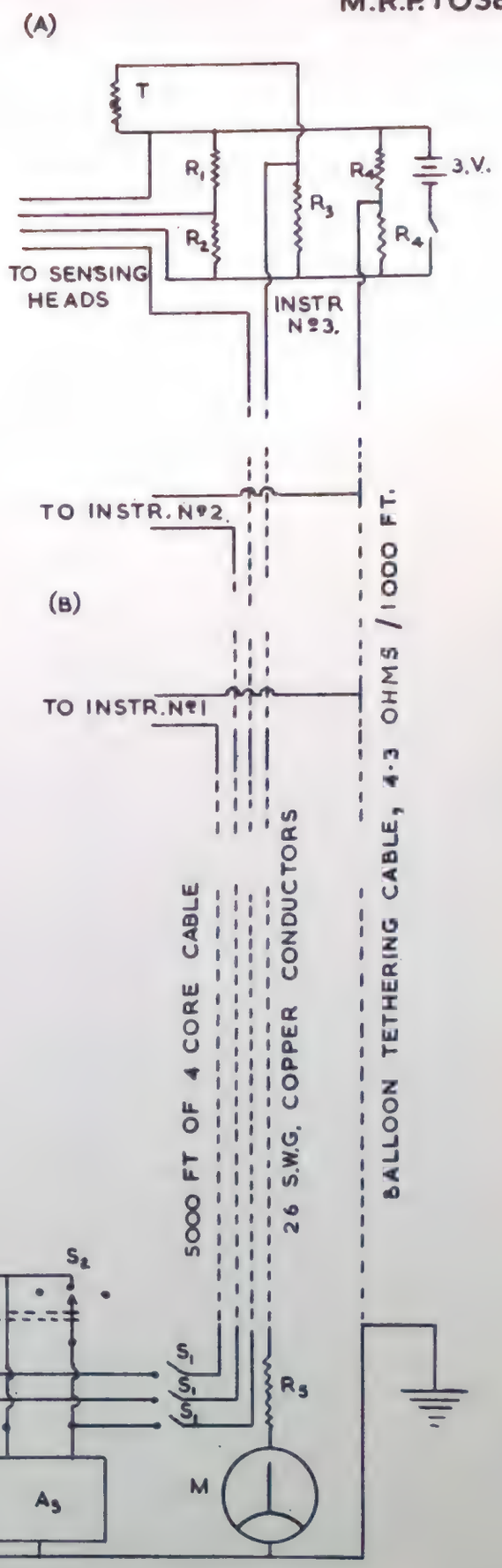


FIG 5. GUSTINESS METER Nº 2 MOUNTED ON BALLOON CABLE.



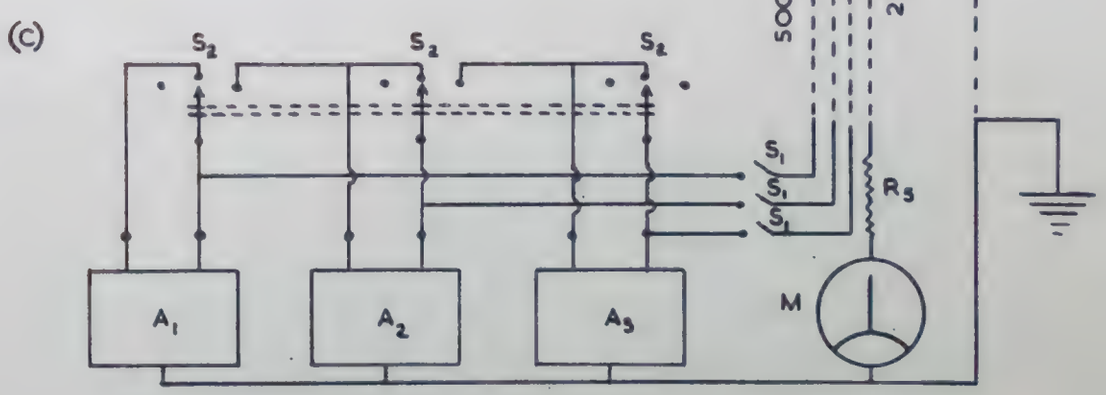


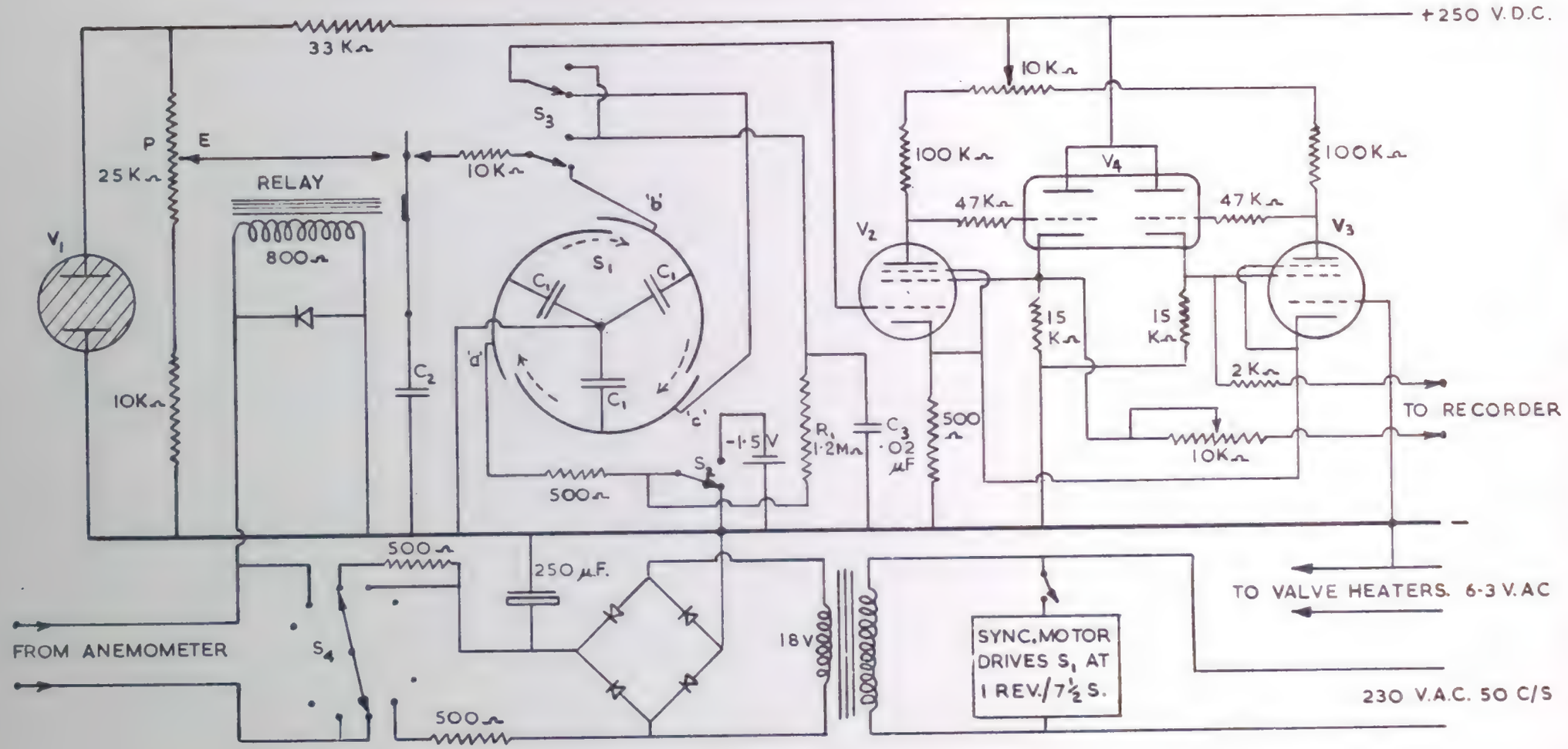
FIG 6. BASIC CIRCUIT SHOWING

(A) CONNECTION OF THERMISTOR INTO CIRCUIT.

(B) USE OF BALLOON CABLE AS COMMON CONDUCTOR.

(C) SWITCHING ARRANGEMENT FOR RECORDING INCLINATION DIFFERENCES.

T = THERMISTOR (K2361/120)
R_1 = 330 Ω. R_4 = 200 Ω.
R_2 = 680 Ω. R_5 = 16280 Ω.
R_3 = 3413 Ω.
M = 20-0-20 μA 1500 Ω.
A_1, A_2, A_3 = AMPLIFIERS.



V_1 = 7475. (VOLTAGE STABILIZER)

V_2 & V_3 = EF 37A.

V_4 = 6 SN 7.

RELAY = SIEMENS TYPE H 73.

C_1 = 2 μF

C_2 = ·001 μF.

FIG: 7

CIRCUIT OF APPARATUS USED WITH OWER ANEMOMETER TO COUNT REVOLUTIONS OVER 2½ SEC. SEQUENTIAL PERIODS.

M.R.P. 1038

Figure 8 shows an example of the limiting of convection in clear air in a ridge of high pressure.

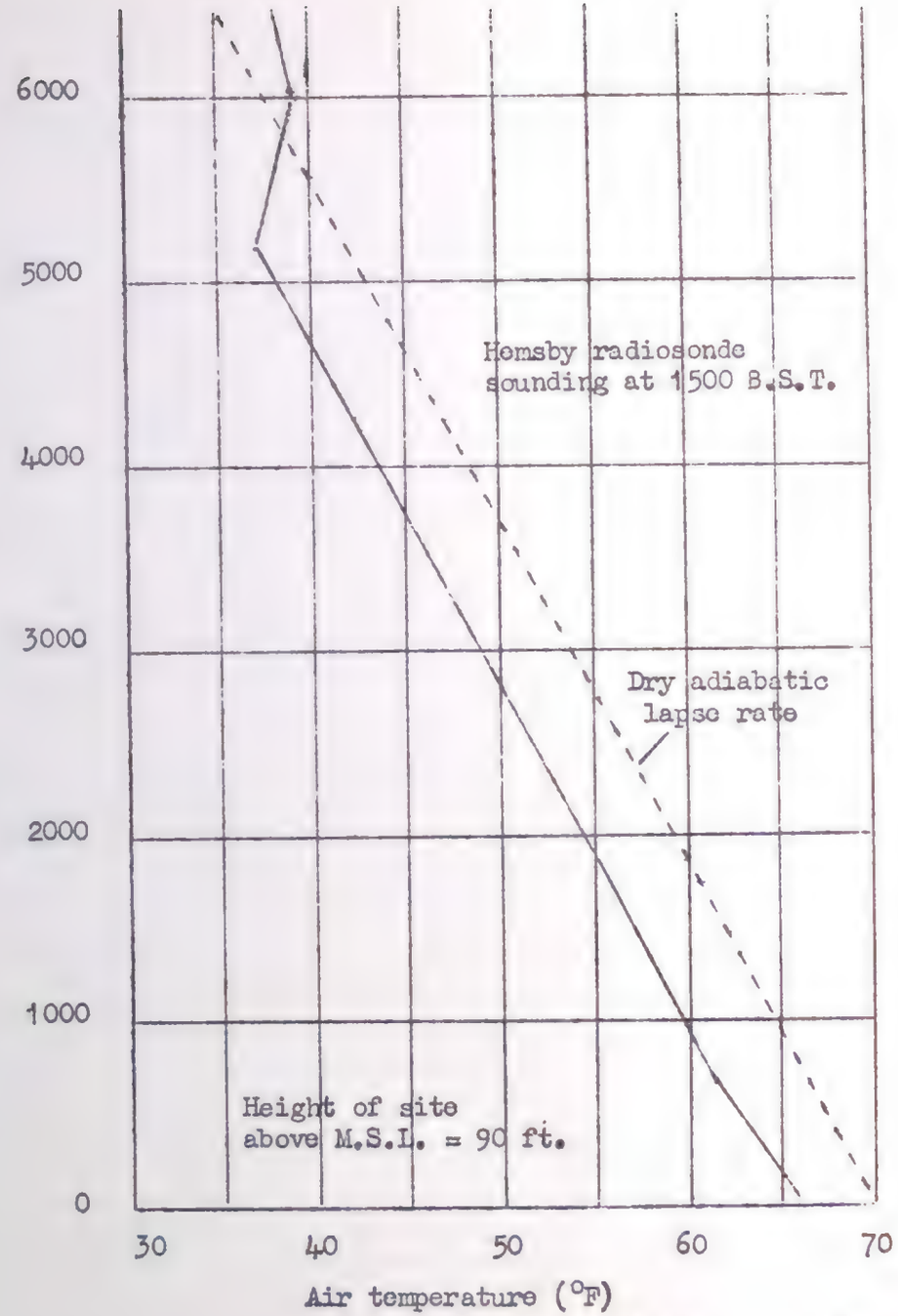
At about 1205 B.S.T. the vane of the lowest gustiness meter was deflected to the limit of its travel.

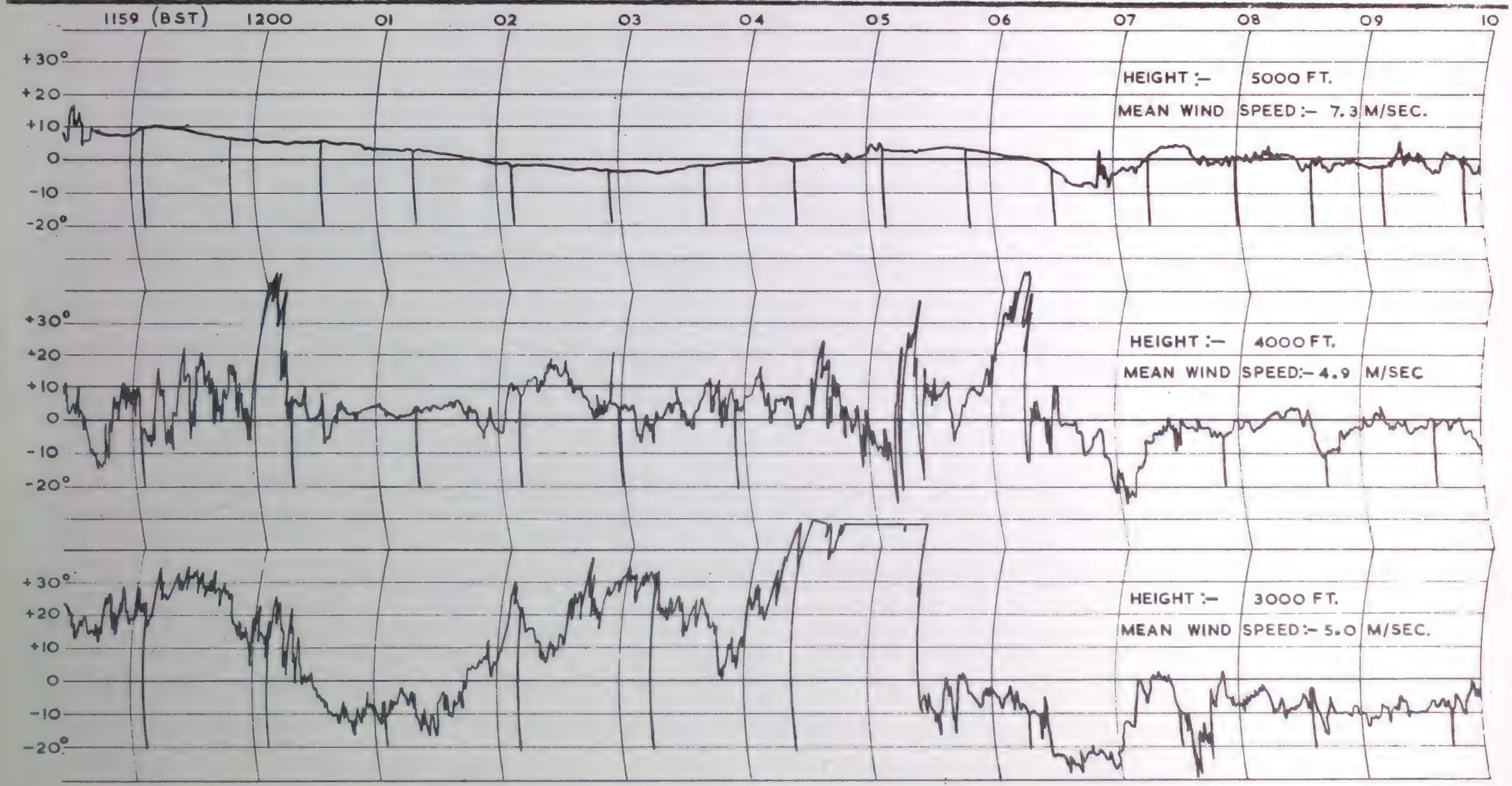
Weather: Sunny

Cloud: $\frac{1}{8}$ Cirrus

$\frac{1}{8}$ Cumulus

Temp. gradient: -2.3°F
(4m. - $\frac{1}{2}$m)





SAMPLE RECORD OF WIND INCLINATION AT 3000, 4000 AND 5000 FEET AT CARDINGTON ON 15 MAY 1956.

FIG: 8

Some root mean square values of wind inclination, in degrees, during the day 27 June 1956

Height	Time B.S.T.	Inclination		Wind speed mean
		Mean	R.M.S.	
1000 feet	0933 - 0953	-3.9	5.2	6.6 m/sec.
	1137 - 1157	+0.7	10.4	6.5 "
	1353 - 1413	-5.3	11.6	6.3 "
	1611 - 1631	-	-	-
	1928 - 1948	-1.5	8.9	1.7 "
2000 feet	0933 - 0953	+0.5	5.3	6.4 m/sec
	1137 - 1157	+0.7	10.6	6.5 "
	1353 - 1413	-8.2	13.9	6.4 "
	1611 - 1631	+1.5	5.1	5.2 "
	1928 - 1948	+1.2	4.1	3.8 "
3000 feet	0933 - 0953	+7.6	5.3	5.0 "
	1137 - 1157	+3.5	8.7	6.3 "
	1353 - 1413	-6.1	10.5	6.3 "
	1611 - 1631	+0.8	5.6	4.4 "
	1928 - 1948	-0.9	2.8	5.8 "

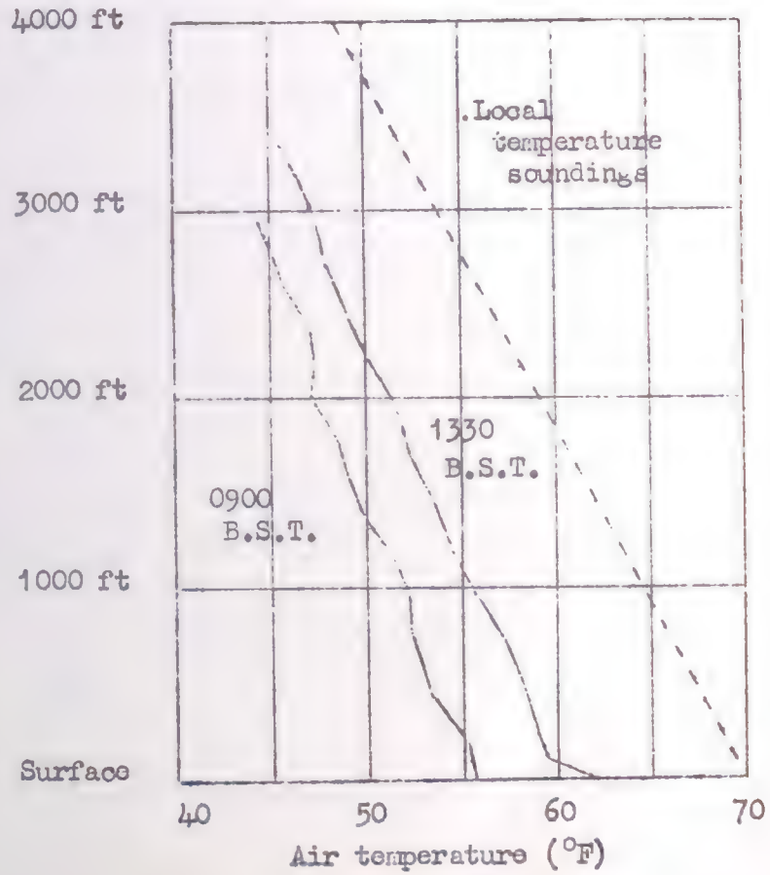
Note: The R.M.S. values are with respect to the 20 min. mean inclination

Figure 9 shows strong convection up to at least 3000 feet in anticyclonic conditions

Weather: Fine

Cloud: 4/8 Cumulus and Stratocumulus base 2500 feet

Temp. gradient: -1.2°F ($\frac{4m.}{} - \frac{1}{2}m.$)



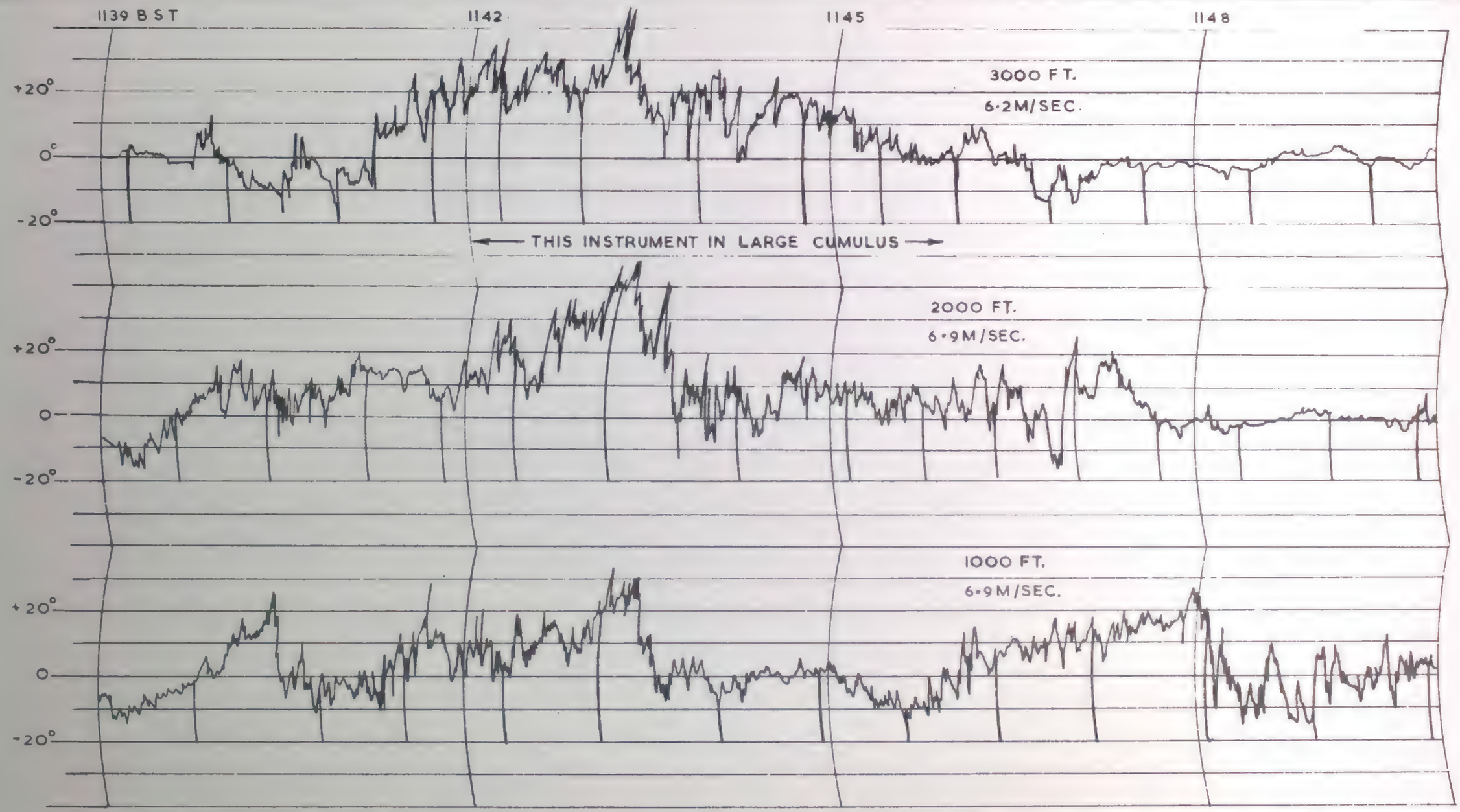


FIG 9. SAMPLE RECORD OF WIND INCLINATION AT 1000, 2000 AND 3000 FEET AT CARDINGTON ON 27 JUNE 1956.

Figure 10 shows the decay of convection in the evening under antiqyclonic conditions

Period commencing 1854 B.S.T.

Weather: Cloudy

Cloud, total: 6/8
low: $\frac{3}{8}$ cumulus and stratocumulus

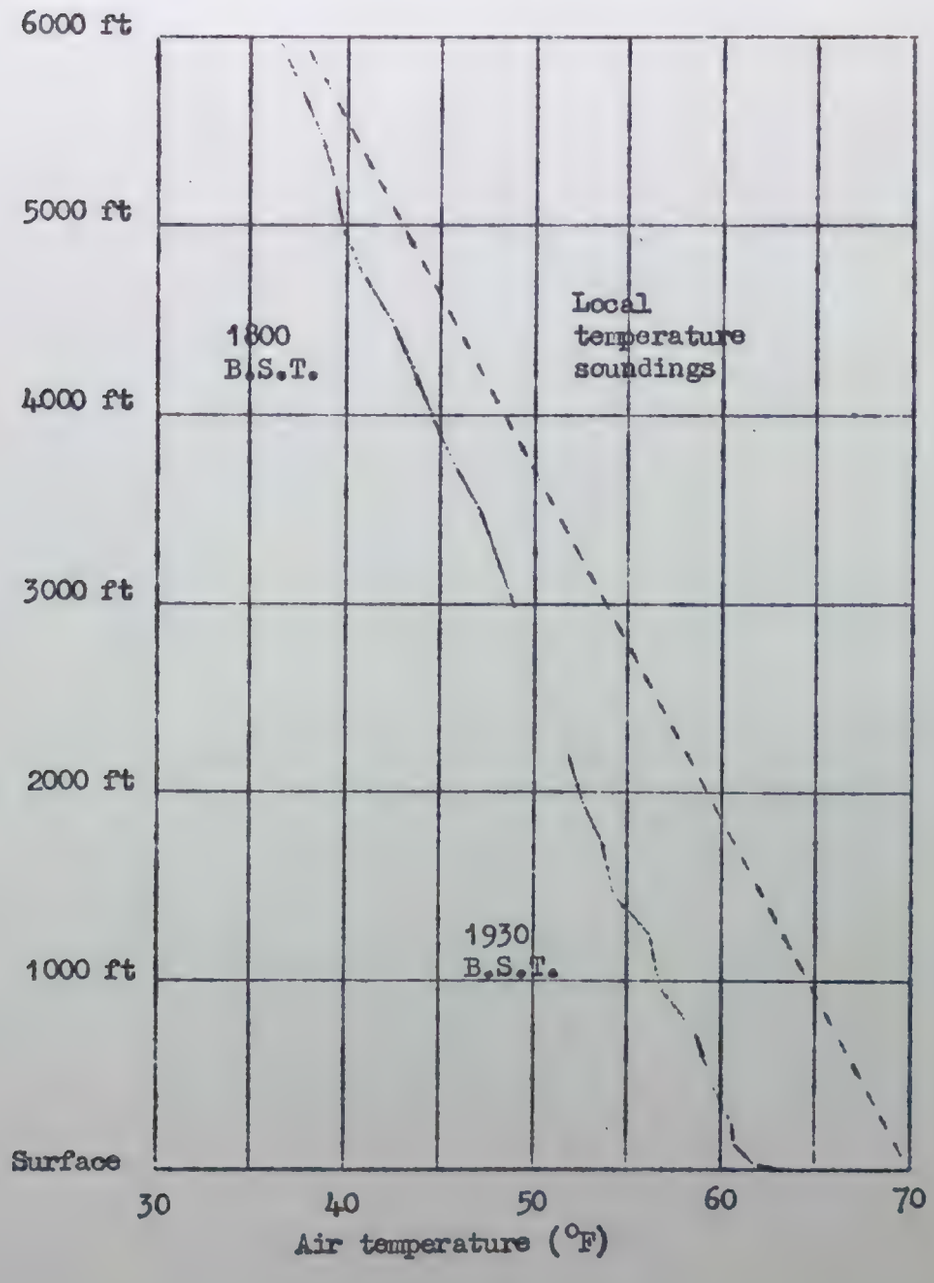
Temp. gradient: +0.1°F
(4m. - $\frac{1}{2}$m)

Period commencing 1934 B.S.T.

Weather: Fair

Cloud, total: $\frac{3}{8}$
low: $\frac{1}{8}$ stratocumulus

Temp. gradient: +0.4°F
(4m. - $\frac{1}{2}$m.)



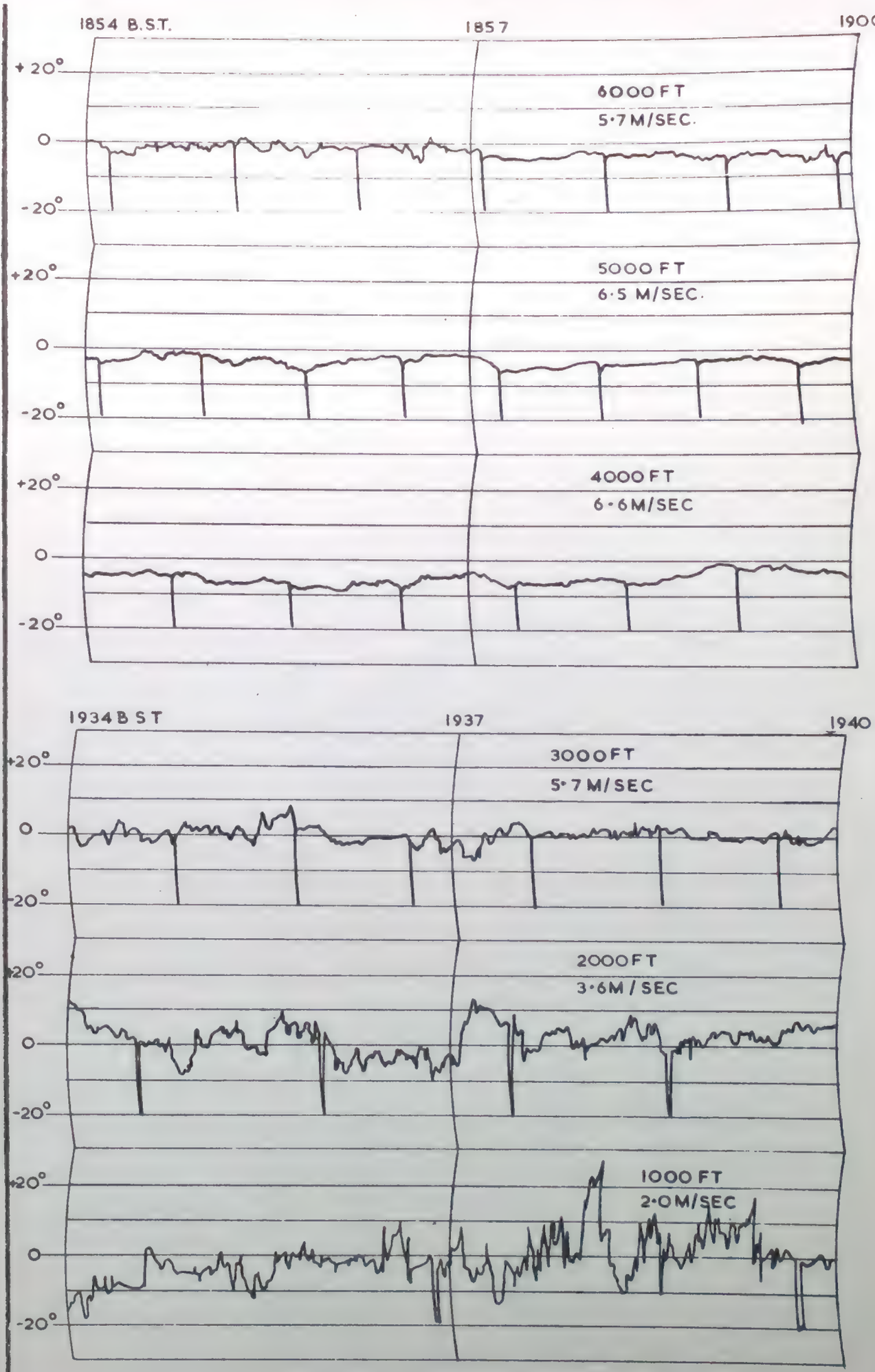


FIG 10. SAMPLE RECORD OF WIND INCLINATION TO 6000 FEET AT CARDINGTON ON 27 JUNE 1956.

Figures 11 and 12 show stable conditions with a warm front approaching from the west

Fig. 11 Period commencing 0454 B.S.T.

Weather: Dull

Cloud: 8/8 Altocumulus and altostratus
$\frac{5}{8}$ Stratus and stratocumulus

Temp: gradient: +0.3°F
($4m_s - \frac{1}{2}m_s$)

Surface wind (20 ft) SW 3 kt.

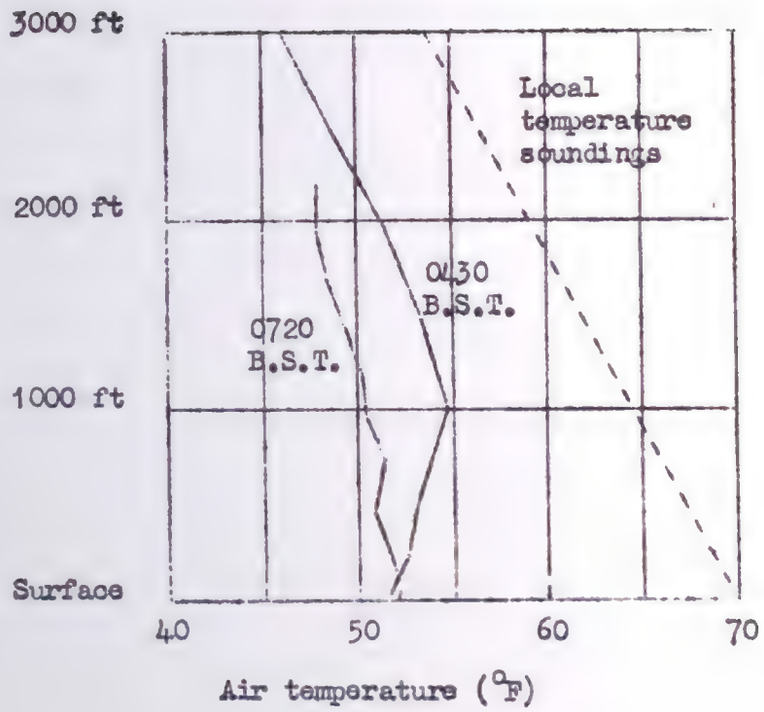
Fig. 12 Period commencing 0653 B.S.T.

Weather: Dull, very slight rain

Cloud: 8/8 Altocumulus and altostratus
$\frac{7}{8}$ Stratocumulus base above 3000 ft.

Temp. gradient: -0.1°F
($4 m_s - \frac{1}{2}m_s$)

Surface wind (20 ft) SW 3 kt.



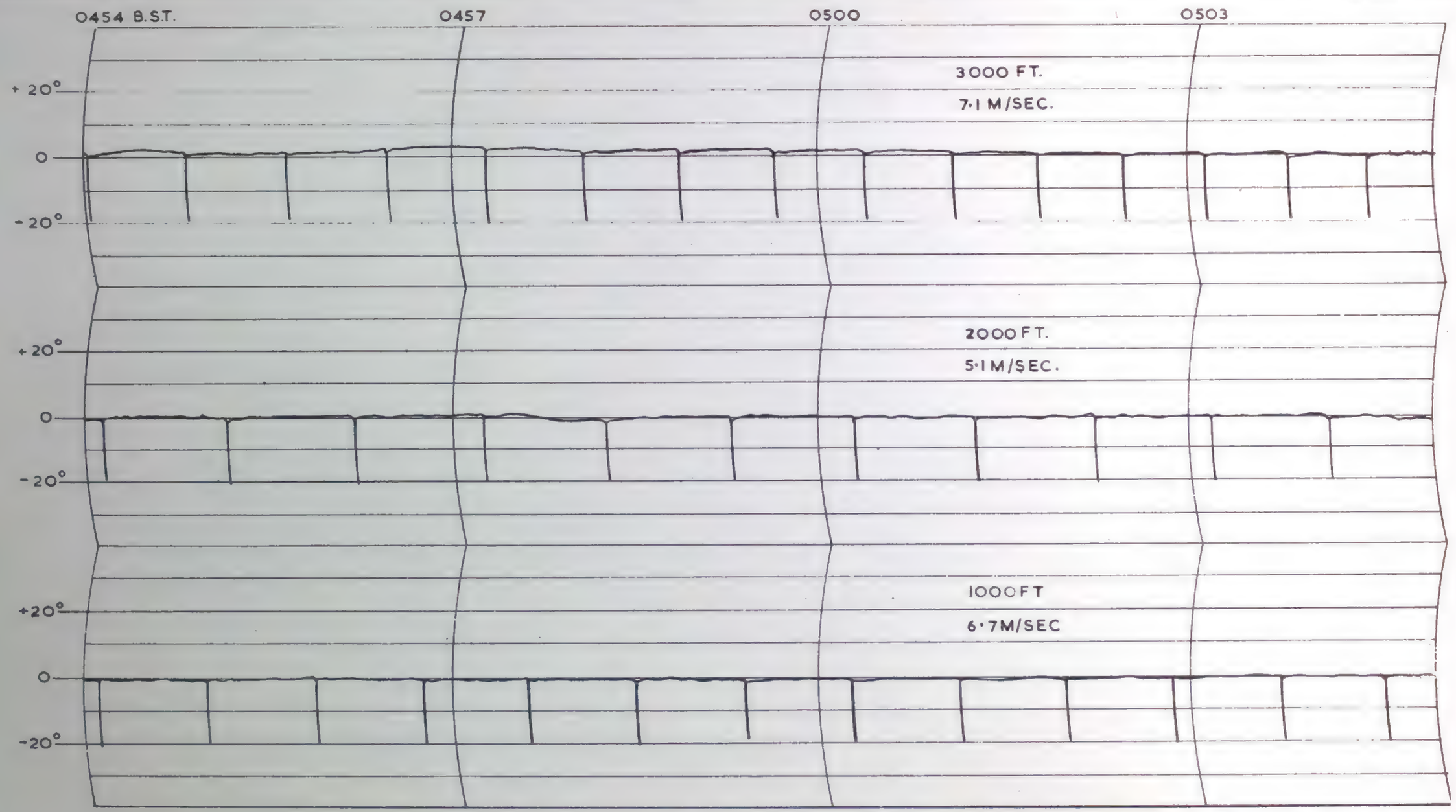


FIG 11. SAMPLE RECORD OF WIND INCLINATION AT 1000, 2000 AND 3000 FEET AT CARDINGTON ON 28 JUNE 1956.

Some root mean square values of wind inclination, in degrees, on 27 June 1956

Height	Time B.S.T.	Inclination Mean	Inclination R.M.S.	Wind speed mean
1000 feet	0453 - 0503	-0.7	0.4	6.7 m/sec.
	0503 - 0513	-0.5	0.4	6.9 "
	0513 - 0523	-0.4	0.5	6.9 "
	0523 - 0533	-0.6	0.7	5.6 "
2000 feet	0453 - 0503	-0.4	0.3	5.1 m/sec
	0503 - 0513	-0.8	0.9	5.4 "
	0513 - 0523	-0.3	0.2	6.0 "
	0523 - 0533	-0.8	1.1	7.5 "
3000 feet	0453 - 0503	+1.1	0.6	6.8 m/sec
	0503 - 0513	+0.1	0.2	8.5 "
	0513 - 0523	+0.6	0.3	9.3 "
	0523 - 0533	+0.2	0.4	10.1 "

Note: The R.M.S. values are with respect to the mean inclination.

For temperature soundings see opposite Fig.11

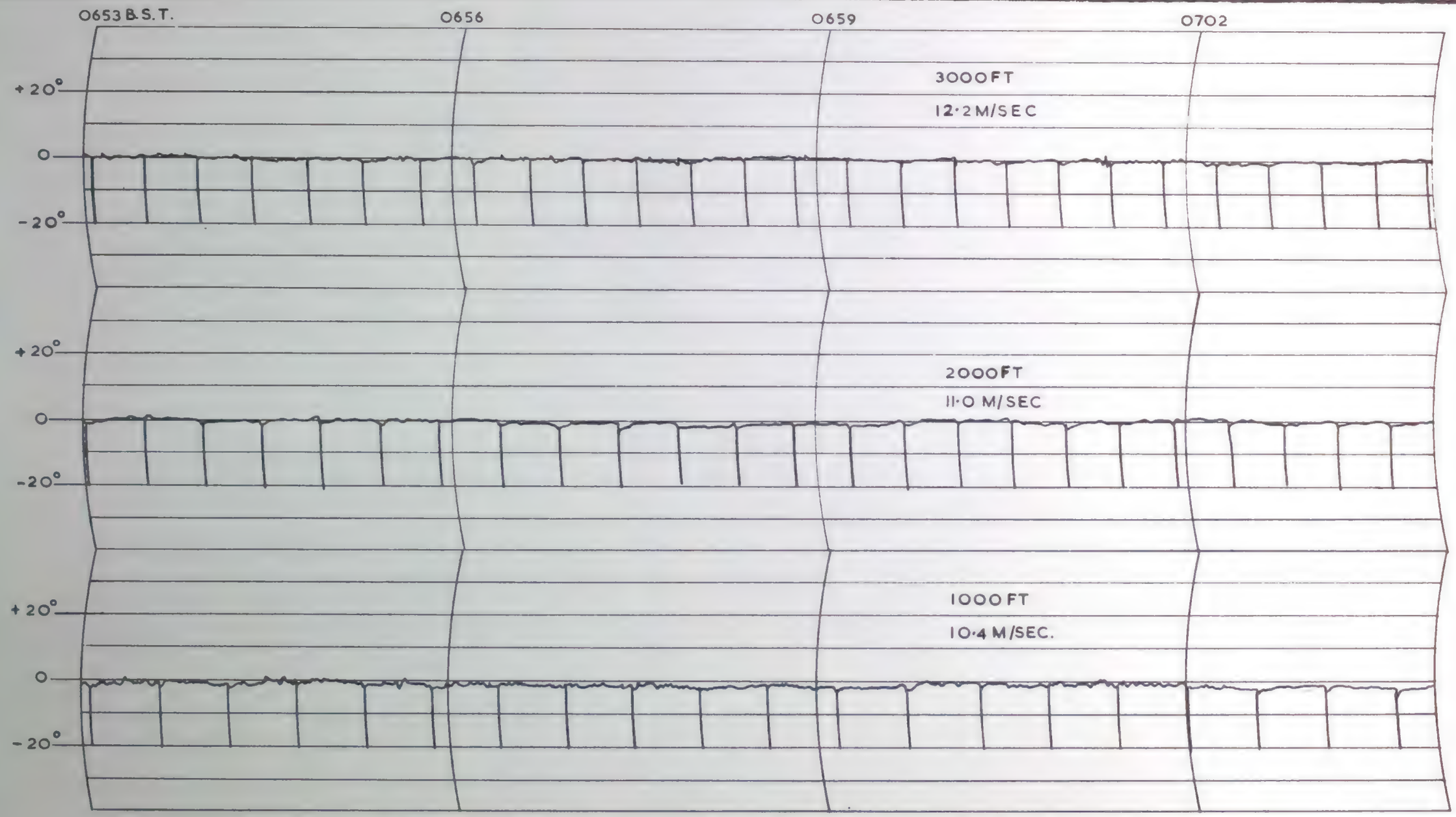


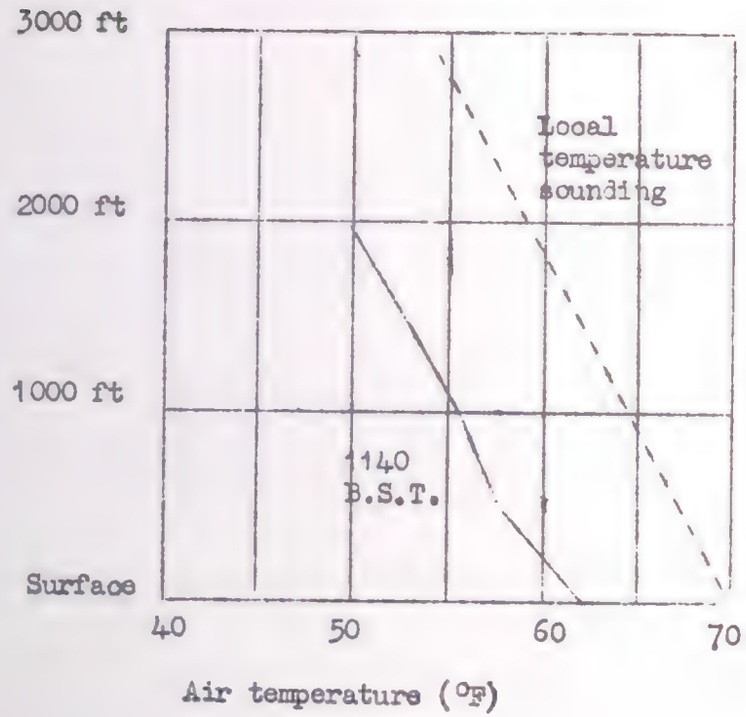
FIG 12. SAMPLE RECORD OF WIND INCLINATION AT 1000, 2000 AND 3000 FEET AT CARDINGTON ON 28 JUNE 1956.

Figure 13 shows an example of a record taken for the calculation of space correlation in warm sector conditions

Weather: Cloudy

Cloud: 8/8 high stratocumulus
4/8 Cumulus and Fractocumulus
base 2500 feet

Temp. gradient: $-0.5^{\circ}F$
$(4m. - \frac{1}{2}m.)$



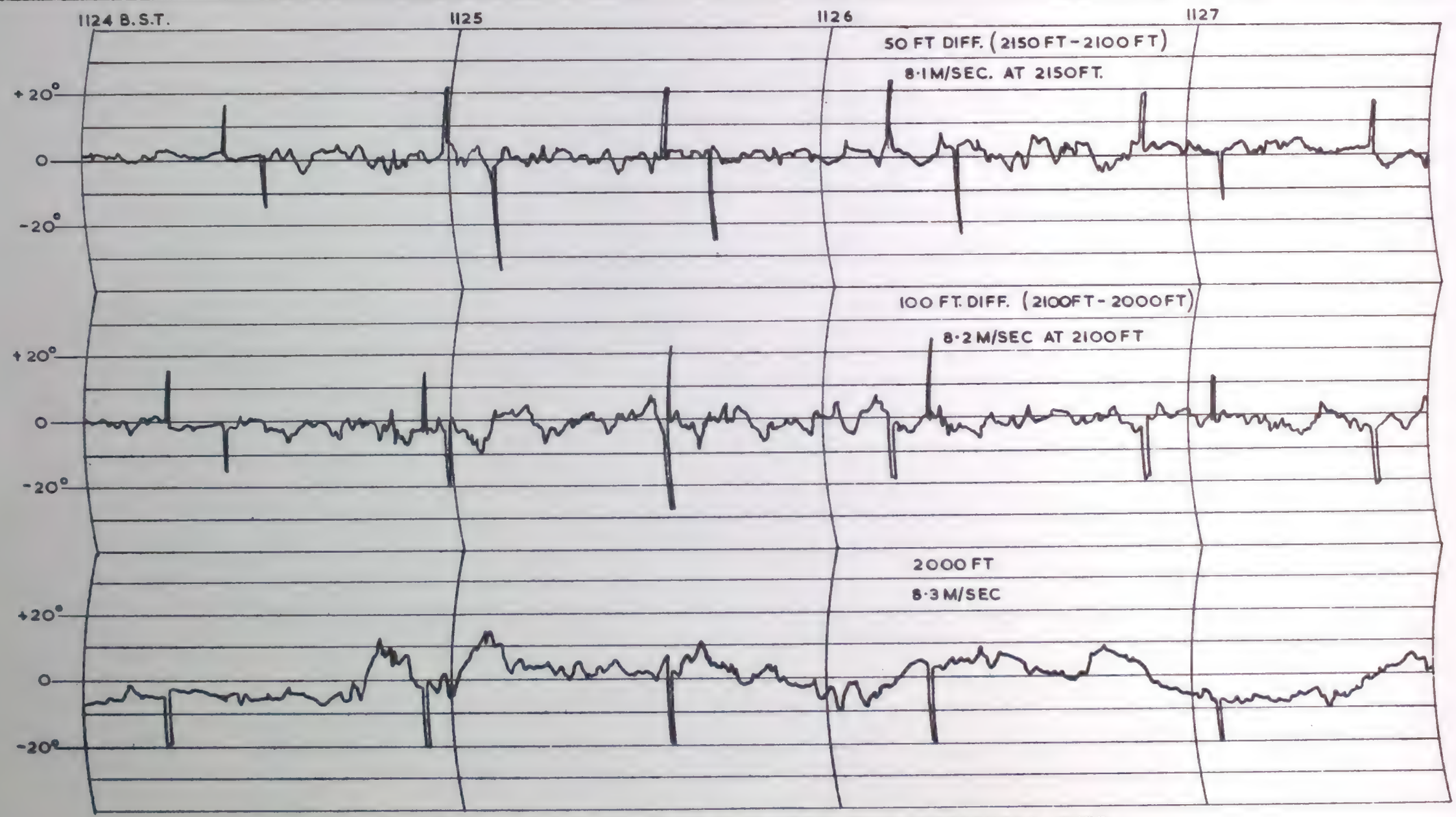


FIG 13.

SAMPLE RECORD OF WIND INCLINATION AT 2000 FEET WITH DIFFERENCES OVER 50 AND 100 FEET AT CARDINGTON ON 30 JUNE 1956.

Figure 14 shows an example of $2\frac{1}{2}$ second means of total wind speed with strong vertical gustiness, in warm sector conditions.

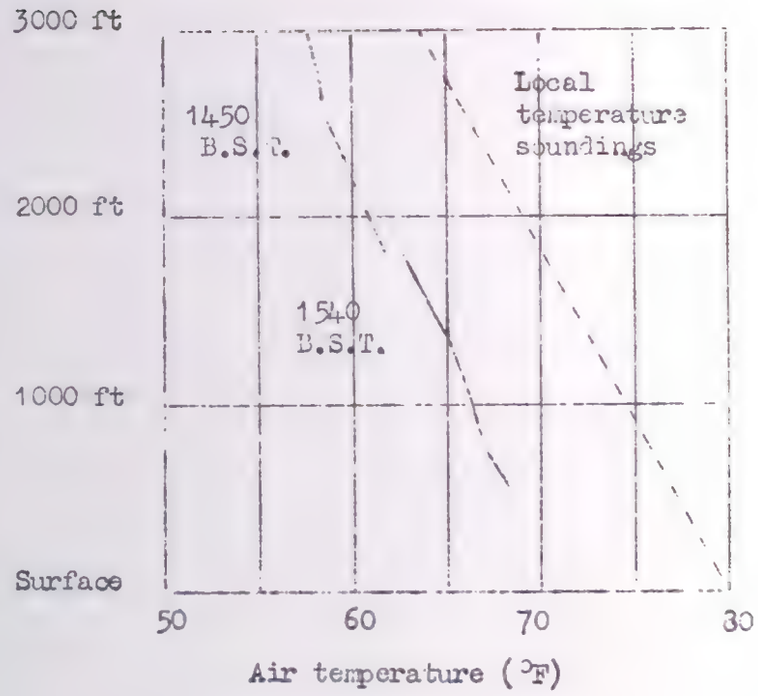
Weather: Sunny

Cloud: Trace Cirrus
2/8 Cumulus

Temp. gradient: +0.1°F
(4m. - $\frac{1}{2}$m.)

Total radiation: +11 m.watts/sq.cm.

Surface wind 3.4 m/sec.



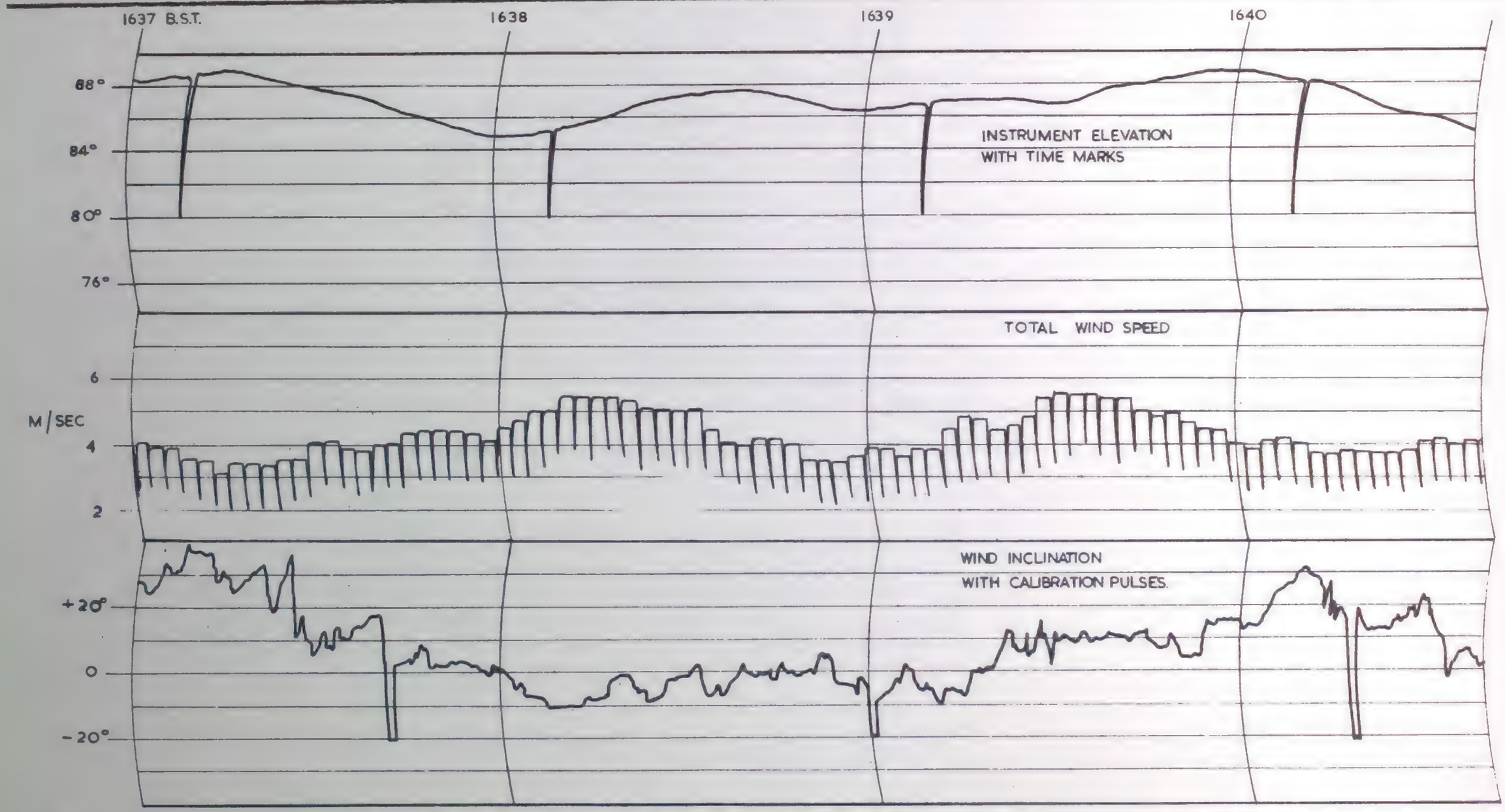


FIG. 14.

SAMPLE RECORD OF WIND INCLINATION, 2½ SECOND MEANS OF TOTAL WIND SPEED, AND ELEVATION OF INSTRUMENT, AT 1500 FEET AT CARDINGTON 13 SEPTEMBER 1956.

Figure 15 shows an example of $2\frac{1}{2}$ second means of total wind speed with small vertical gustiness in a ridge of high pressure

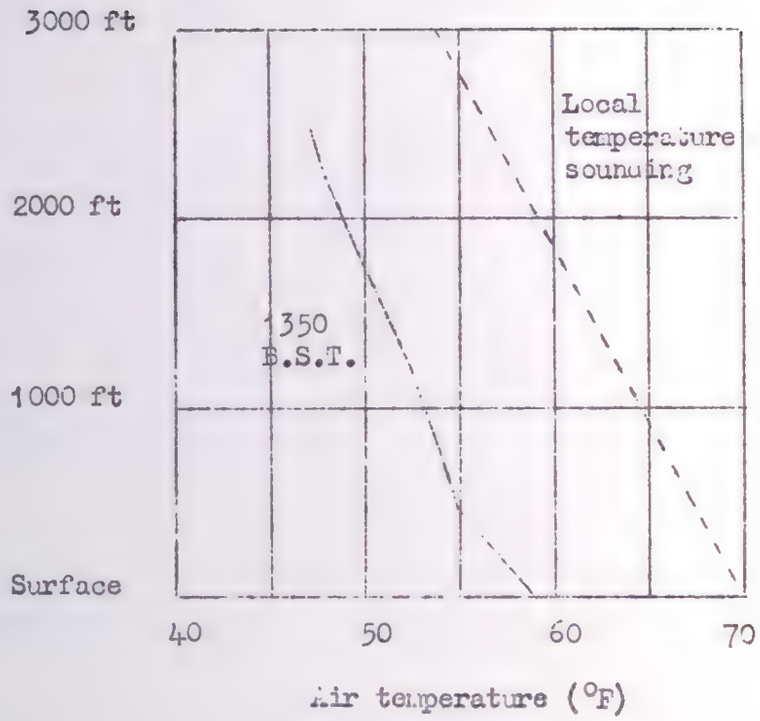
Weather: Cloudy

Cloud: 8/8 Stratocumulus, base 3000 ft

Temp. gradient: 0.0°F
(4m. - $\frac{1}{2}$m.)

Total radiation: +3 m.watts/sq.cm.

Surface wind: 5.2 m/sec.



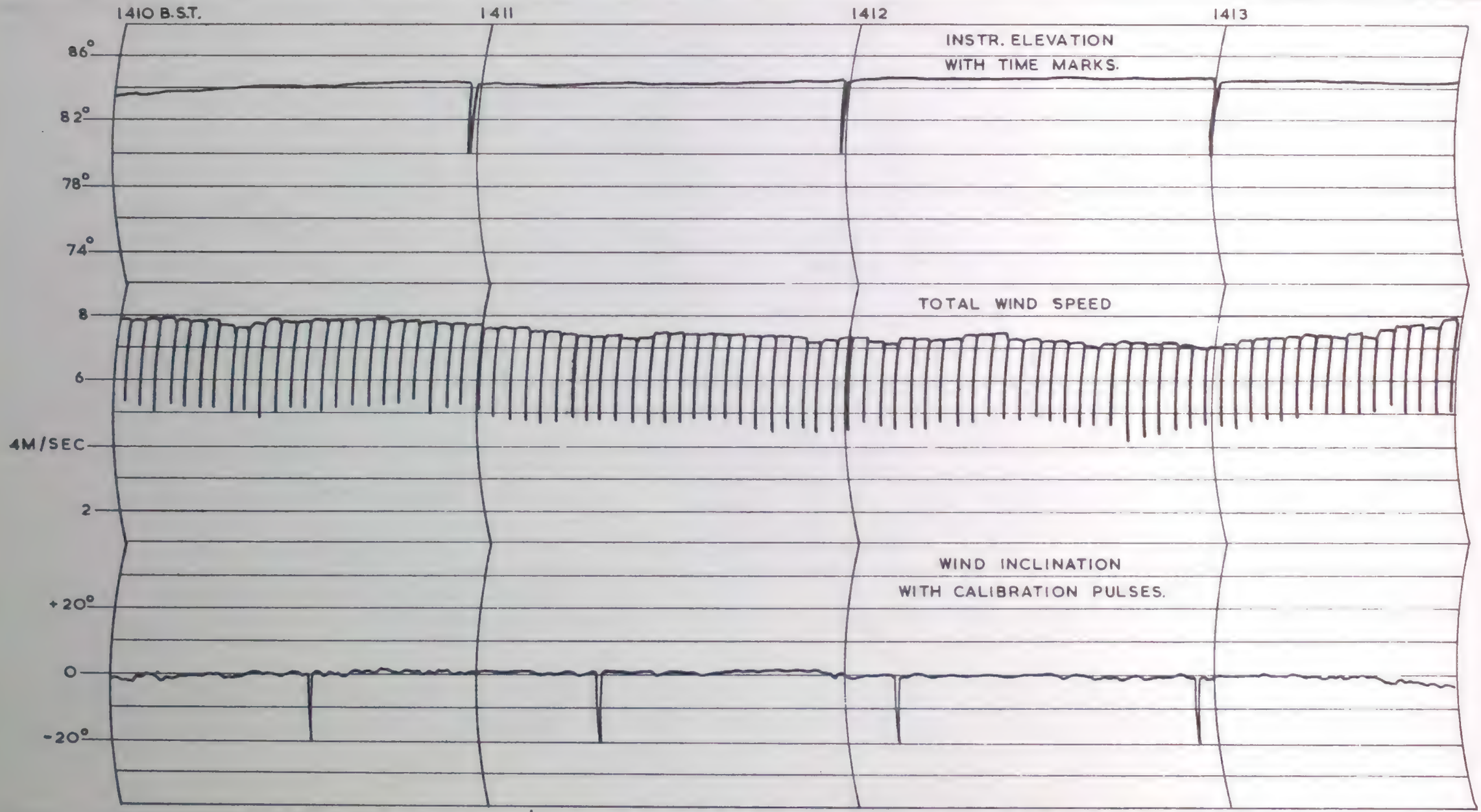


FIG. 15. SAMPLE RECORD OF WIND INCLINATION, 2½ SECOND MEANS OF TOTAL WIND SPEED, AND ELEVATION OF INSTRUMENT, AT CARDINGTON ON 16 SEPTEMBER 1956. (AT 2900 FT.)

Figure 16 shows an example of continuous total wind speed with small vertical gustiness in a ridge of high pressure

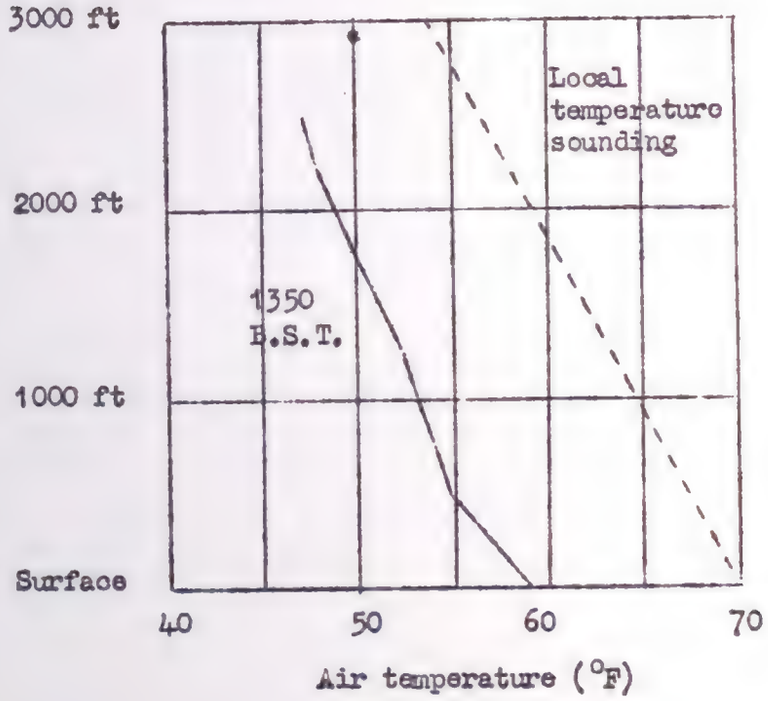
Weather: Cloudy

Cloud: 8/8 Stratocumulus, base 2500 ft.

Temp. gradient: 0.0°F
(4m. - ½m.)

Total radiation: +3 m.watts/sq.cm.

Surface wind: 5.7 m/sec.



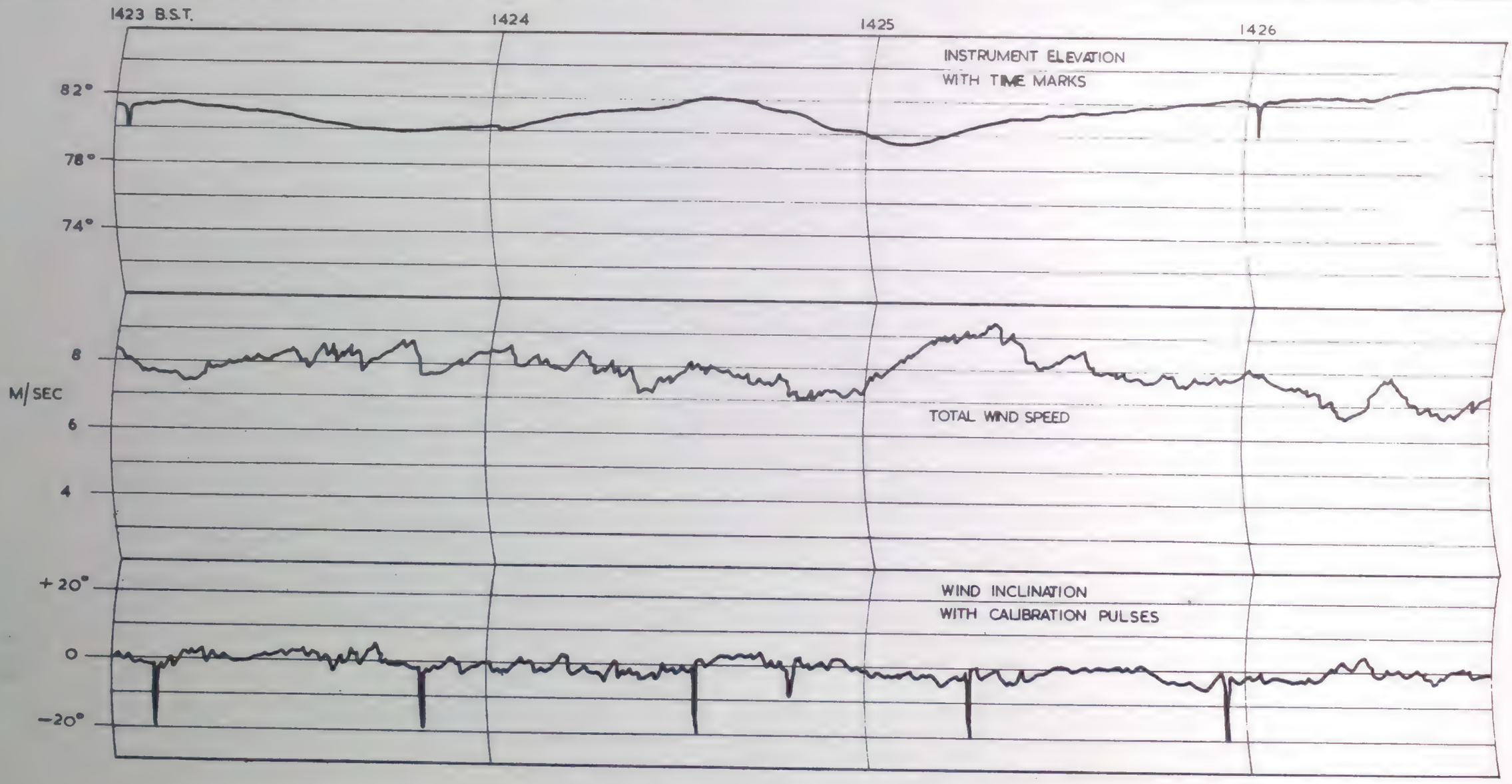


FIG. 16

SAMPLE RECORD OF WIND INCLINATION, TOTAL WIND SPEED, AND ELEVATION OF INSTRUMENT, AT 2,000 FEET AT CARDINGTON ON 16 SEPTEMBER 1956

Figure 17 shows turbulence to a limited height in a ridge of high pressure. See also Fig.18

Weather: Cloudy

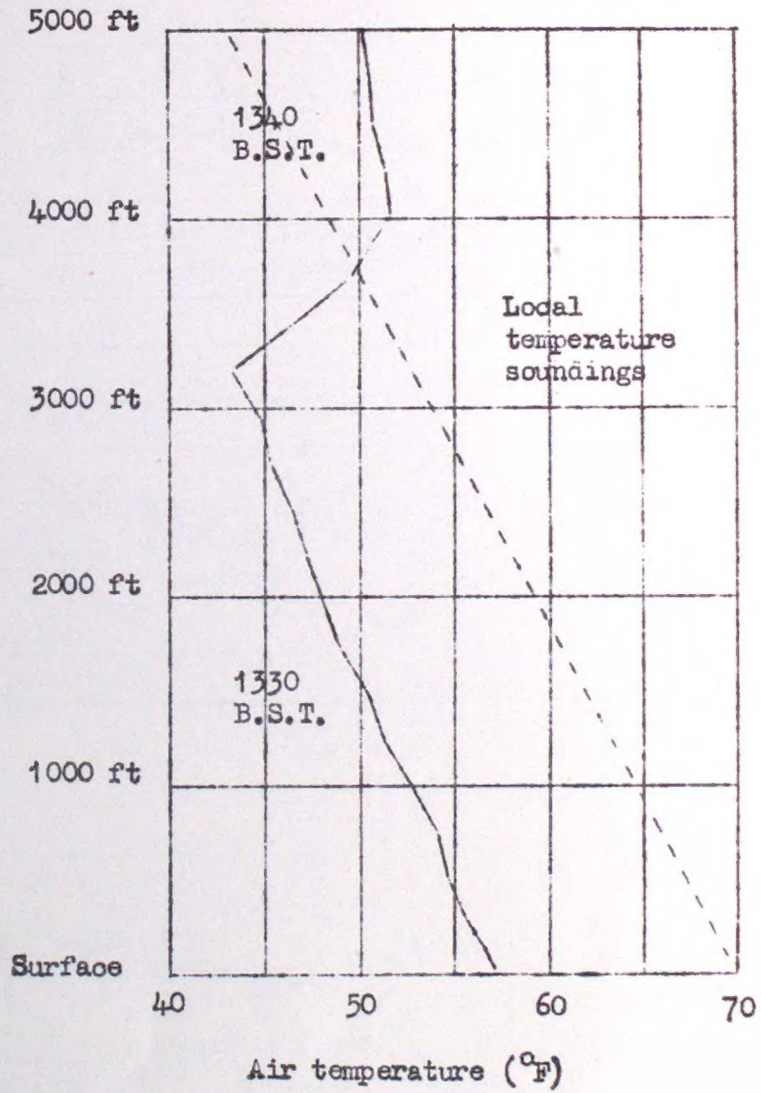
Cloud: 6/8 Stratocumulus

Temp. gradient: -0.6°F
(4m. - ½m.)

Total radiation: 11 m.watts/sq.cm.

Surface wind: 3.6 m/sec.

See Fig. 18 for sample record
at 5000, 6000 and 7000 ft.



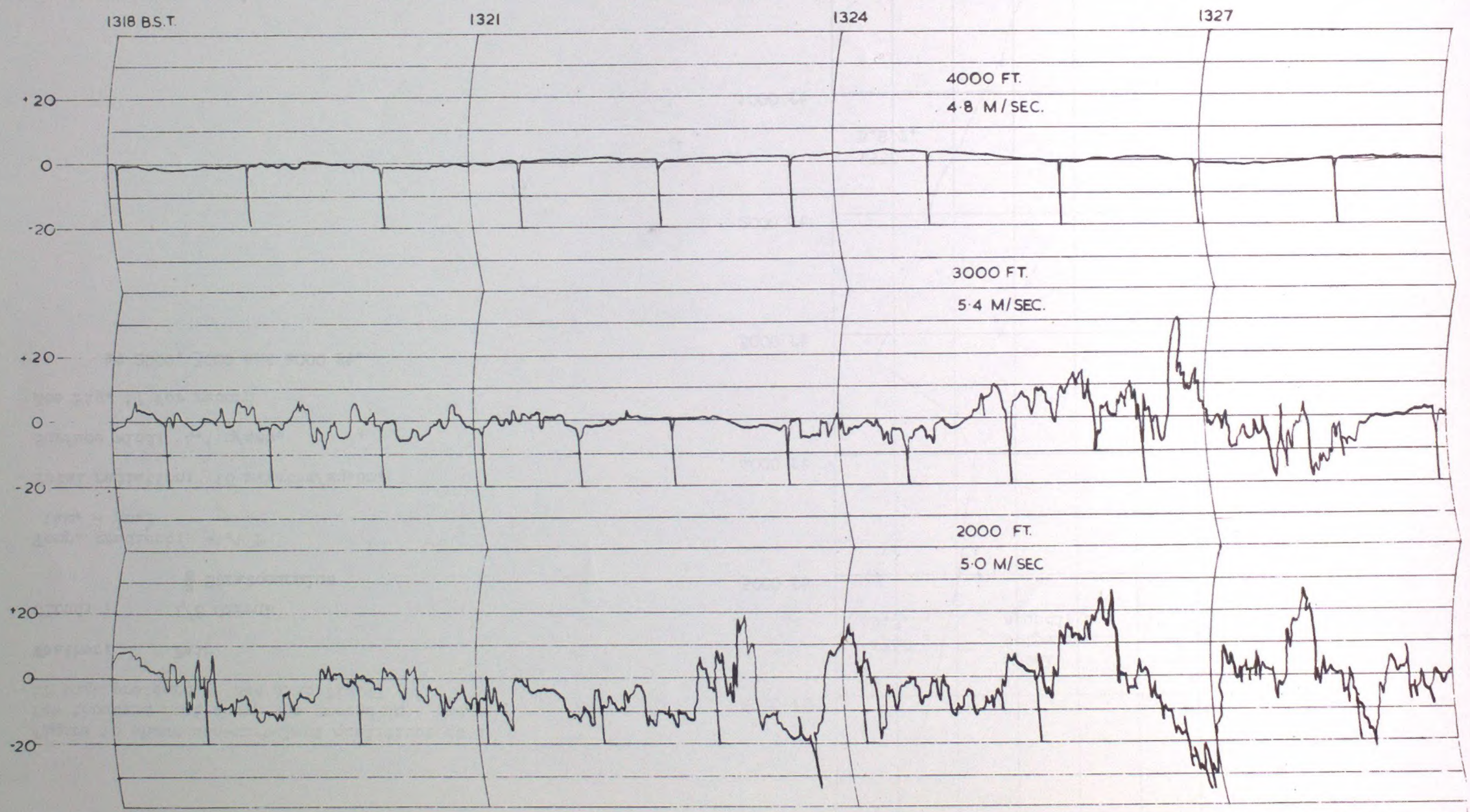


FIG. 17 SAMPLE RECORD OF WIND INCLINATION AT 2000, 3000 AND 4000FT. AT CARDINGTON ON SEPT. 17TH. 1956

Figure 18 shows non-turbulent conditions at a few thousand feet above the ground in a ridge of high pressure. See also Fig.17

Weather: Fair

Cloud: 2/8 Cirrus
$\frac{3}{8}$ Stratocumulus

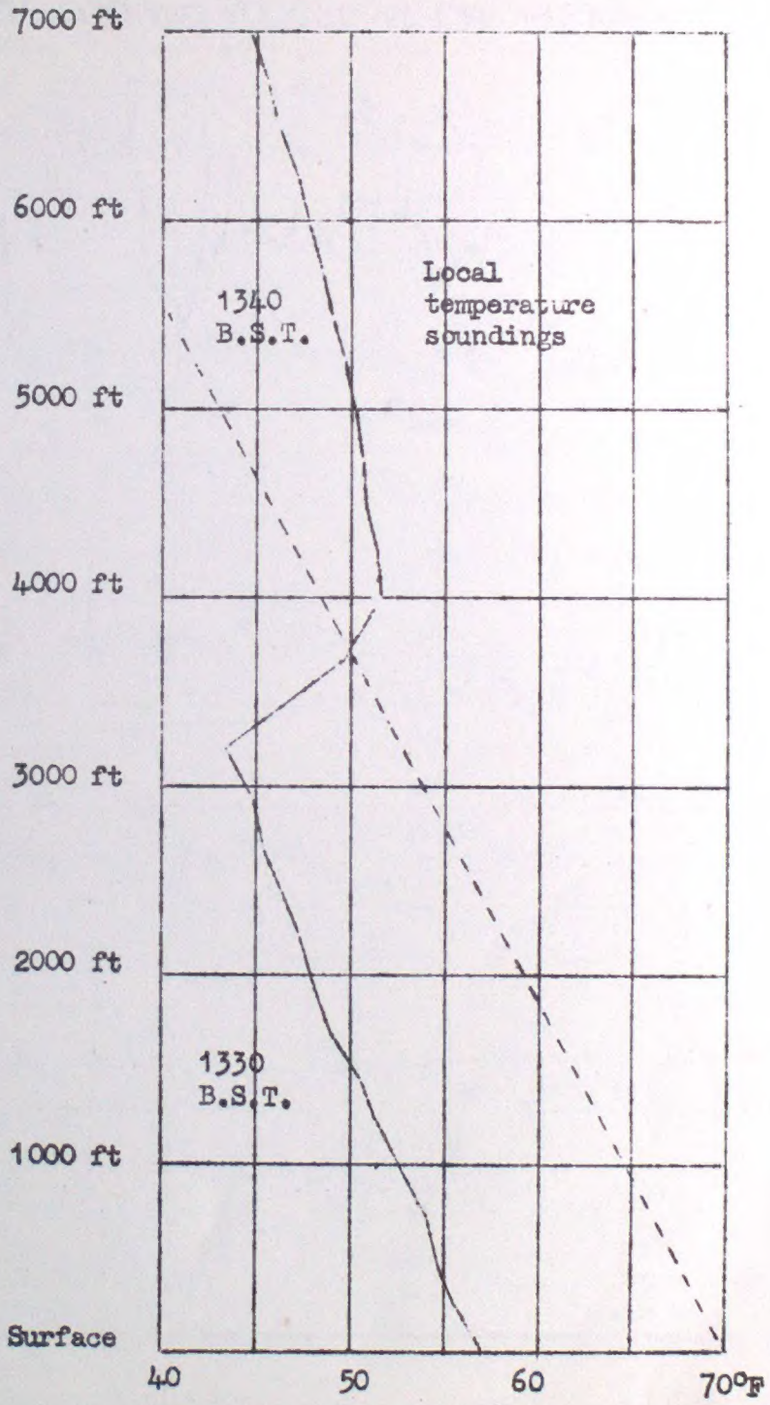
Temp. gradient: -1.1°F
($4m. - \frac{1}{2}m.$)

Total radiation: 18 m.watts/sq.cm.

Surface wind: 4.1 m/sec.

See Fig. 17 for record

at 2000, 3000 and 4000 ft.



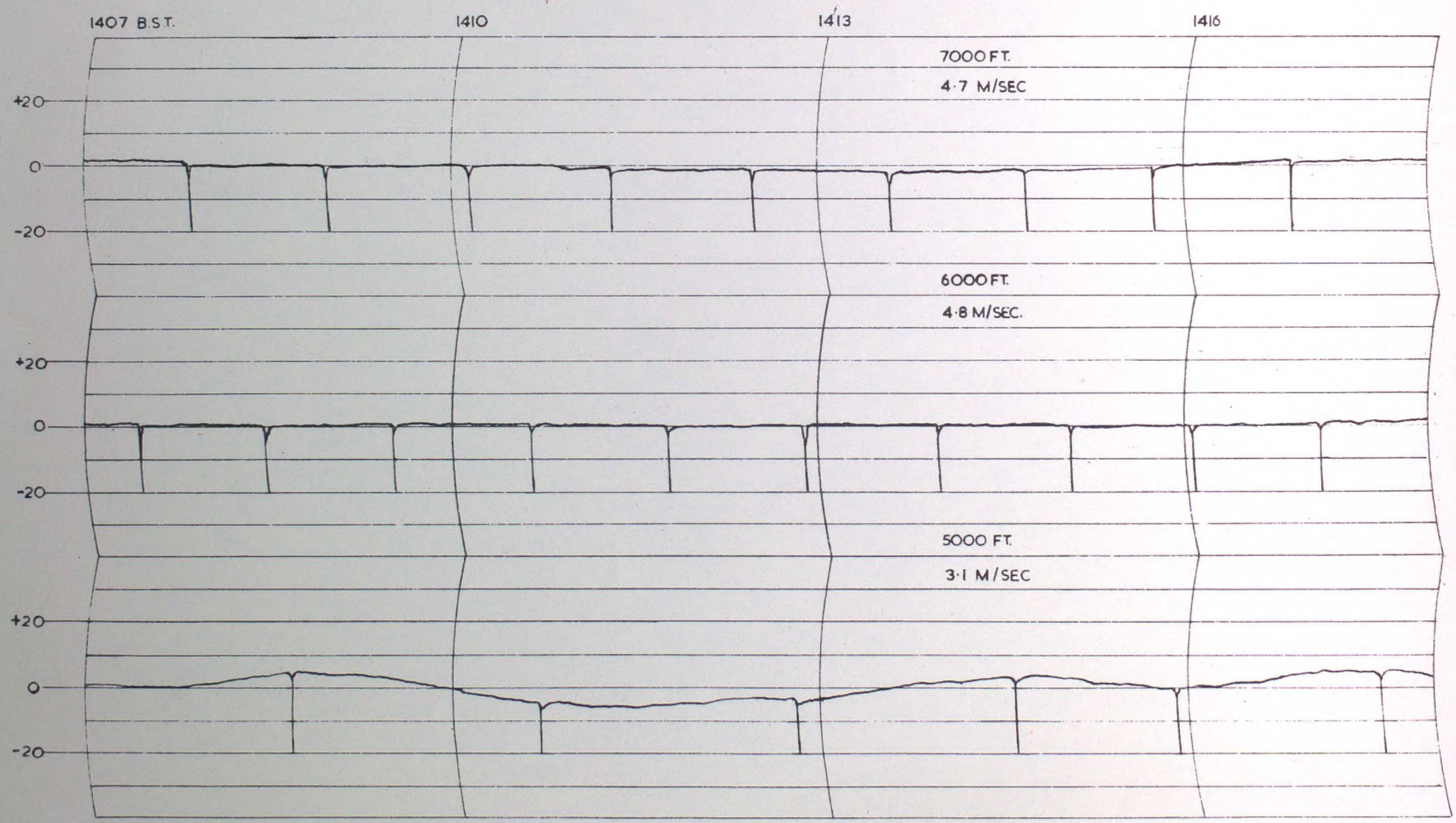


FIG. 18 SAMPLE RECORD OF WIND INCLINATION AT 5000, 6000 AND 7000FT. AT CARDINGTON ON SEPT. 17. 1956